PB86-183092

Evaluation of a Fluidized-Bed Sewage Sludge Incinerator Using Wood Chips for Fuel

Systech Corp., Xenia, OH

Prepared for

Environmental Protection Agency, Cincinnati, OH

Apr 86

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-183092

EPA/600/2-86/044
April 1986

EVALUATION OF A FLUIDIZED-BED SEWAGE SLUDGE INCINERATOR USING WOOD CHIPS FOR FUEL

by

Ned J. Kleinhenz and Gary Smith

SYSTECH Corporation
Xenia, Ohio 45385

Cooperative Agreement No. R806144

Project Officer

Howard Wall
Wastewater Research Division
Water Engineering Research Laboratory
Cincinnati, Ohio 45268

WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/2-86/044		PB86 183092/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
Evaluation of a Fluidized-Bed Sewage Sludge Incinerator Using Wood Chips for Fuel	April 1986
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Ned J. Kleinhenz and Gary Smith	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Systech Corporation Xenia, Ohio 45385	D.U. B-113 CAZB1B
	11. CONTRACT/GRANT NO.
	R806144
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Water Engineering Research Laboratory, Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: Howard Wall FTS (513) 684-7645 Com. 569-7659

16. ABSTRACT

An environmental and technical evaluation was conducted on the Western Lake Superior Sanitary District waste treatment plant, which uses wood chips to incinerate sewage sludge in fluidized-bed combustors. The most important environmental factors for evaluation were determined to be the metal contents of the particulate stack emissions and of various influent and effluent streams to the combustor scrubber system.

The technical evaluation used data collected over the life of the facility to develop a mathematical model of the incineration and energy recovery system. The model was coded in the form of a computer program and can rapidly evaluate a wide variety of possible situations in which such an energy recovery approach might be taken. Thus, the technical evaluation is presented in a widely usable and understandable form.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	Unclassified	99
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	$ 11.95

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency (EPA) under Assistance Agreement No. R-806144 to Western Lake Superior Sanitary District. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Development of safe and economical methods for disposing of sewage sludges and other wastes is a most pressing need. This publication provides information on the emissions to the atmosphere resulting from the burning of sewage sludge using wood wastes as a supplemental fuel. The process uses fluidized-bed incineration and recovers heat using package designed waste heat boilers which are separate units from the fluidizing-bed furnaces.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

An environmental and technical evaluation was conducted on the Western Lake Superior Sanitary District waste treatment plant, which uses wood chips to incinerate sewage sludge in fluided-bed combustors. The most important environmental factors for evaluation were determined to be the metal contents of the particulate stack emissions and of various influent and effluent streams to the combustor scrubber system.

The technical evaluation used data collected over the life of the facility develop a mathematical model of the incineration and energy recovery system. The model was coded in the form of a computer program and can rapidly evaluate a wide variety of possible situations in which such an energy recovery approach might be taken. Thus, the technical evaluation is presented in a widely usable and understandable form.

This report was submitted in fulfillment of Cooperative Agreement No. R806144 by SYSTECH Corporation for the Western Lake Superior Sanitary District under the sponsorship of the U.S. Environmental Protection Agency.

CONTENTS

Foreword iii
Abstract iv
Figures vii
Tables viii
Metric Conversion Table. x

1. Introduction 1
   Test Objectives 2
   Test Overview 3
2. Summary and Conclusions 5
   Summary of Average Metal Mass Rates 5
   Summary of Mass Process Steam Ratees 5
   Summary of Operating Problems 8
   Summary of Particulate Emission 9
   Conclusions 10
3. Test Procedures and Plant Description 14
   Overview 14
   Sewage Sludge Filter Cake 14
   Wood Chips (Fuel) 17
   Fluidized-Bed Sand 17
   Fly Ash 17
   Scrubber System 18
   Stack Emissions Tests 21
   Stack Sampling Quality Assurance 21
   Sample Digestion 22
4. Results and Discussions 24
   Wood Chips 24
   Sludge Filter Cake 27
   Sand 28
   Fly Ash 28
   Scrubber 29
   Scrubber Particulate Removal Efficiency 33
   Scrubber Metal Concentrations 33
   Determination of Stack Mass Rate 35
   Stack Metals Emissions 37
   Operating Problems 38
   Sludge Feed System 38
   Ash Handling System 46
   Fly Ash Slagging 50
5. Discussion of Mathematical Model of the Combustor System . . . 52
   Introduction 52

CONTENTS (continued)

Operating the Program 53
Available Modes 54
Stored Values 55
Energy Balance Display 59
Other Program Operating Notes 61
Appendix A. Basic Design Data 63
Appendix B. NBS-Fly-Ash 66
Appendix C. HEATBAL Computer Model 68

FIGURES

Number		Page
1.	WLSSD process schematic	4
2.	Metal analysis sampling locations	15
3.	Belt press mass balance	16
4.	Scrubber system	19
5.	Scrubber mass balance	20
6.	Scrubber water balance (lb/hr)	36
7.	Scrubber ash balance (lb/hr)	39
8.	Sludge feed nozzle	45

TABLES

Number		Page
1	Summary of Average Metal Mass Rates (g/hr)	6
2	Total Mass Rates (lb/hr)	7
3	Water Mass Rates (lb/hr)	8
4	Ash Mass Rates (lb/hr)	9
5	Particulate Emissions Rates	10
6	Elemental Composition (Percent) of Output Streams to Total Input	11
7	Average Elemental Composition (Percent) of Major Process Streams	13
8	Detection Limits for Elemental Determinations By ICPES	23
9	Wood Chip Composition and Mass Rate	25
10	Metals Concentrations in Wood Chips (μ/g dry solids)	26
11	Wood Chip Metal Rate (g/hr)	27
12	Belt Press Data	28
13	Sludge Filter Cake Composition	29
14	Metals Concentrations in Sludge Filter Cake (μ/g)	30
15	Sludge Metal Mass Rate (g/hr)	31
16	Metals Concentration in Sand	32
17	Sand, Metal Mass Rate (g/hr)	33
18	Metals Concentration in Fly Ash (μ/g)	34
19	Fly Ash Metal Mass Rate (g/hr)	35

TABLES (continued)

Number		Page
20	Flue Gas Moisture to Scrubber	37
21	Scrubber Solids and Mass Rates	38
22	Metals Concentrations in Scrubber Influent (µg/ml)	40
23	Metals Concentrations in Scrubber Discharge (µg/ml).	41
24	Metals Concentrations in Scrubber Overflow (µg/ml)	42
25	Scrubber Influent Metal Mass Rate (g/hr)	43
26	Scrubber Discharge Metal Mass Rate (g/hr)	43
27	Scrubber Overflow Metal Mass Rate (g/hr)	44
28	Stack Data and Mass Rates	46
29	Total Metals in Probe Wash Plus Particulate Filter	47
30	Metals Concentration in Impinger Catch	48
31	Particulate Metal Mass Rate (g/hr)	49
32	Impinger Catch Metals Mass Rate (g/hr)	49
33	Stored Values	56

METRIC CONVERSION TABLE

Multiply	By	To obtain
Cubic feet per minute	472.0	cubic centimeters per second
Cubic yards	0.7646	cubic meters
Degrees Fahrenheit -32	5/9	degrees Centigrade
Feet	0.3048	meters
Gallons (U.S. liquid)	3.785×10^3	liters
Horsepower	1.014	horsepower (metric)
Inches of H_2O	25.40	kilograms per square meter
Pounds	453.6	grams
Square miles	2.590	square kilometers
Tons (short, mass)	907.2	kilograms

SECTION 1

INTRODUCTION

The Western Lake Superior Sanitary District (WLSSD) serves the 500-square-mile* area surrounding Duluth, Minnesota, which is a major port on Lake Superior. The District provides wastewater treatment (44 million gal/day) and solid waste disposal (280 tons/day [TPD]) for approximately 135,000 area residents.

The WLSSD waste treatment plant was designed by Consoer, Townsend and Associates in 1975. This plant incorporated several new and innovative technologies to accomplish the co-incineration of the solid wastes and sewage sludge. The incineration facility (completed in 1979) was designed to use shredded solid waste as fuel (refuse-derived fuel or RDF) to augment the combustion of the sewage sludge in one of two fluidized-bed combustors (FBCs), each rated at 100 million Btu/hr and having a 21-ft bed diameter. A major portion of the energy required to operate the facility was provided by a waste-heat boiler that produces steam from energy in the hot combustion gases. Basic design data for the system and the associated wastewater treatment facilities are presented in Appendix A.

The U.S. Environmental Protection Agency (EPA) Office of Solid Waste Management and Municipal Environmental Research Laboratory awarded a research evaluation grant (No. R-806-144010) to WLSSD to compile information on the technical, environmental, and economic performance of this innovative co-disposal system. Subsequently, in December 1978, WLSSD contracted with SYSTECH Corporation to perform that research evaluation.

In 1979, a detailed plan of study was developed by SYSTECH, and a technician was located in Duluth, Minnesota, to prepare for data collection and monitoring of the co-disposal system. Technical difficulties were experienced by WLSSD in the operation of the refuse processing system and the fluidized-bed combustors. These technical difficulties prevented the continuous operation necessary to perform data collection and monitoring for the research evaluation.

In March 1980, the research evaluation was postponed while WLSSD planned and performed numerous modifications to the solid waste processing system and to the FBC. By December 1983, WLSSD was still experiencing difficulties with the solid waste processing system, and further major modifications were still

* Units used in this paper reflect terminology common to the industry. Metric conversion table is presented on page viii.

being made. In the absence of RDF, wood or bark chips were used as an auxiliary fuel. Since the research evaluation had already been delayed 5 years, it was decided to complete as much of the evaluation as possible with the system in its present configuration.

TEST OBJECTIVES

The original objectives of the research grant were to perform a technical, environmental, and economic evaluation of the refuse sludge co-combustion process at WLSSD. Because of the 5-yr delay, caused principally by difficulties encountered with the refuse processing portion of the facility, the specific tests and analyses to be performed were confined to fluidized-bed incineration system. In light of the aforementioned difficulties, the objectives were also modified to emphasize the technical and environmental evaluation. A process specific economic evaluation was judged to be unsuitable because the original design is still undergoing modifications to remedy problems associated with the RDF system and the development of a fuel distribution system to feed the RDF into the fluidized bed. The specific program objectives and are outlined below.

Because the energy recovery, co-combustion system has a very limited number of effluent streams, it was decided that the most important environmental evaluation factors were the stack particulate emissions and especially the metal content of those particulate emissions and of the various influent and effluent streams to the combustor scrubber system. The scrubber operates in a recycle mode taking make-up (scrubber influent) from the treatment plant and discharging the total scrubber effluent back to the treatment system. Thus it is conceivable that the metals picked up in the scrubber water could, when returned to the treatment plant, have a toxic or inhibitory impact on the biological processes. Thus the fate of metals in the process became the most important consideration in the environmental evaluation of this process.

As a result of the extensive evaluation performed on the combustion process over the life of the facility, much of the information needed to perform the technical evaluation was already available. Thus, it was decided that this information could best be used by developing a mathematical model of the incineration and energy recovery system and to code this model in the form of a computer program. This model could readily be used by WLSSD personnel and by others in the technical community. By varying several of the input parameters (e.g., fuel characteristics, sludge characteristics, and energy demand) as described in Section 5 of this document, it is possible to use this model to perform rapid technical evaluation of a wide variety of possible situations in which such an energy recovery approach might be taken. Actual operating data were used as the basis for developing this model, and the performance of the combustor for various operating scenarios can be predicted through the use of this model. This approach presents the technical evaluation of the combustion and energy recovery system in a widely usable and understandable form.

Since the fluidized-bed approach using wood chips or possibly processed refuse as primary fuel for the combustion of sewage sludge may be considered by other communities, insights into operating and design difficulties encountered have been highlighted.

TEST OVERVIEW

Figure 1 illustrates the current configuration of the incineration system. Detailed descriptions of subsystems relevant to this investigation are provided in Section 3.

To collect metals data, sewage sludge was co-incinerated with wood chips in the fluidized-bed reactor under the same set of normal operating conditions on April 10, 11, and 12, 1984. Representative hourly samples of each of seven major process streams were acquired over a 6-hr test period during the 3 days. Hourly samples of each process stream were composited to provide one representative daily sample of each stream for metal analyses. The mass flow rate of each process stream was measured or calculated, and the metals concentrations within each stream were calculated. In addition, operating logs of 1982, 1983, and 1984 were analyzed to produce the data needed to design those equations that describe the mass and energy flows of the incineration and heat recovery system.

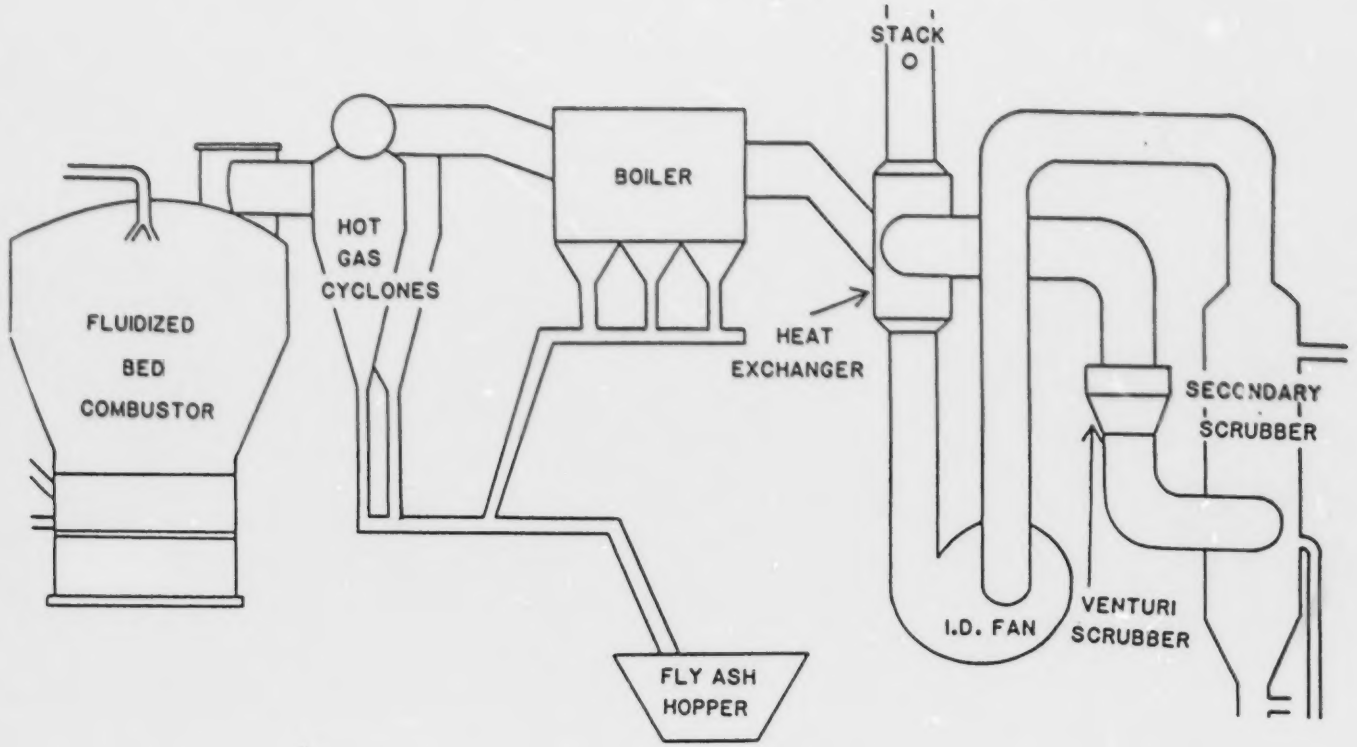


Figure 1. WLSSD process schematic.

SECTION 2

SUMMARY AND CONCLUSIONS

SUMMARY OF AVERAGE METAL MASS RATES

Table 1 presents the average mass rates of metals detected within the various process streams. Elements entering the system with the sludge filter cake (SC), wood chips (WC), and the fluidizing-bed sand (SA) are summed in the fourth column (Σ In). The elements are listed in decreasing order of magnitude of total system input. Exponential notation has been used to allow quick scanning for order of magnitude differences. Dashes indicate that the concentration of the reported element was below the analytical detection limit in one, two, or all three of the samples analyzed.

Metals leave the incineration system via the fly ash (FA), net flow to the scrubber from the incinerator (ΔS), and the stack particulate (PF and IC). As explained in detail in Sections 3 and 4, the net scrubber discharge is the result of subtracting the mass rate of metals entering the scrubber via the scrubber influent (SI) from the mass rate of metals in the scrubber overflow (SO) and the scrubber discharge (SD). Thus

$$\Delta S = (SO + SD) - SI$$

The total mass rate of metals leaving the system is then

$$\Sigma \text{ Out} = FA + \Delta S + PF + IC$$

Qualitatively it can be noted that the majority of the elements show more mass entering the system than leaving.

SUMMARY OF MASS PROCESS STREAM RATES

Tables 2, 3, and 4 present a summary of the daily mass rates for each stream as regards total mass, mass of water, and mass of ash, respectively. Concentrations of metals within these streams are presented in Section 4. From Tables 2 and 3, the dry sludge feed rates to the combustors during the test were calculated to be 2504, 2862, and 2005 lb/hr, respectively.

Quality assurance results for analysis of National Bureau of Standards (NBS) fly ash reference samples and EPA reference sludge samples indicate good analytical accuracy and precision for the concentration measurements. Random measurement errors and process variability were quantified jointly with

TABLE 1. SUMMARY OF AVERAGE METAL MASS RATES (g/hr)

Elements	Sludge filter cake	Wood chips	Bed sand	Σ In	Fly ash	Scrubber water influent	Scrubber over-flow	Scrubber dis-charge	Net scrubber discharge	Particu-late filtrable	Impin-ger catch	Σ Out
Ca	2.16E04*	4.14E04	1.15E03	6.42E04	2.09E04	1.56E04	3.69E03	2.22E04	1.03E04		---	3.12E04
Al	3.13E04	3.40E02	1.07E03	3.27E04	2.70E04	4.66E01	2.29E01	1.15E02	9.13E01		2.19E00	2.71E04
P	1.43E04	1.30E03	1.24E01	1.56E04	3.80E03	---	---	---	---	9.54E-01	---	3.80E03
K	7.20E03	6.15E03	2.86E02	1.36E04	1.35E04	1.19E03	2.90E02	1.16E03	2.60E02	2.24E00	---	1.38E04
Ti	1.23E04	4.91E01	1.55E02	1.25E04	1.87E03	---	---	2.11E01	---	1.72E-01	---	1.89E03
Fe	9.23E03	5.78E02	1.15E03	1.10E04	9.91E03	1.79E02	2.16E02	1.59E02	1.96E02	1.69E-01	---	1.01E04
S	9.51E03	1.52E03	9.16E00	1.10E04	8.86E02	4.63E03	1.21E03	8.80E03	5.38E03	1.59E00	3.49E01	6.30E03
Mg	6.13E03	2.59E03	3.44E02	9.06E03	5.33E03	3.32E03	7.92E02	3.55E03	1.02E03	---	---	6.35E03
Na	3.02E03	8.57E02	2.67E02	4.14E03	2.60E03	3.80E04	8.73E03	3.00E04	7.30E02	---	1.60E01	3.44E03
Zn	1.26E03	3.26E02	1.81E00	1.59E03	8.91E02	6.53E00	2.22E00	1.89E01	1.46E01	---	---	9.06E02
Ba	5.15E02	1.89E02	7.25E02	7.11E02	3.54E02	1.96E01	5.45E00	4.49E01	3.08E01	3.91E-02	2.86E-01	3.85E02
Mn	3.64E02	1.44E02	1.78E01	5.26E02	3.15E02	4.72E01	1.69E01	7.77E01	4.74E01	3.41E-02	---	3.62E02
Cu	2.02E02	1.11E01	1.47E00	2.15E02	1.13E02	---	---	9.63E00	9.63E00	---	---	1.23E02
Pb	1.44E02	---	5.54E-01	1.45E02	--	---	---	---	---	---	---	---
Sr	6.88E01	5.71E01	2.67E00	1.29E00	6.75E01	2.35E01	5.58E00	3.11E01	1.32E01	4.49E-03	---	8.07E01
Cr	3.91E01	---	2.67E00	4.18E01	3.90E01	---	---	---	---	---	---	3.90E01
V	3.84E01	---	3.44E00	4.18E01	2.01E01	---	---	---	---	---	---	2.01E01
Ni	3.38E01	---	1.22E00	3.50E01	2.21E01	---	---	---	---	1.45E-02	---	2.21E01
Co	2.99E01	---	8.40E-01	3.07E01	8.73E00	---	---	---	---	---	---	8.73E00
Si	2.34E01	---	1.36E00	2.48E01	3.79E02	1.73E03	4.27E02	2.39E03	1.09E03	1.26E00	4.23E01	1.51E03
Mo	1.20E01	---	1.87E-01	1.22E01	1.48E00	---	---	---	---	---	---	1.48E00
B	---	---	3.82E00	3.82E00	5.76E01	---	---	---	---	---	---	5.76E01
Li	---	---	---	2.75E00	---	---	---	---	---	---	---	2.75E00
Be	7.09E-01	---	---	7.09E-01	---	---	---	---	---	---	---	---
Cd	---	---	1.91E-01	1.91E-01	---	---	---	---	---	---	---	---

* Results reported in computer notation, e.g., 2.16E04 = 2.16×10^4 = 21, 600

† Dashes indicate that the concentration of the reported element was below the detection limit in one, two, or all three of the samples analyzed

TABLE 2. TOTAL MASS RATES
lb/hr

Item	Test Number 1	2	3	$\bar{X}$*	S†	% total
Input						
Sludge (filter cake)	15,362	18,114	13,544	15,673	2,300	3
Wood	13,351	13,745	10,790	12,629	1,604	2
Dry combustion air	91,738	101,790	77,747	90,425	12,075	16
Moisture in combustion air	917	1,018	777	904	121	<1
Atomizing steam	1,000	1,000	1,000	1,000	-0-	<1
Scrubber influent	449,280	449,280	473,242	457,267	13,834	79
Sand	42	42	42	42	-0-	<1
Total Input	571,690	584,989	577,142	577,940	6,689	
Output						
Fly ash	683	627	578	636	53	<1
Scrubber overflow	91,136	83,878	151,883	108,966	37,344	19
Scrubber discharge	374,400	384,384	335,962	364,915	25,566	65
Dry flue gas	83,900	85,700	86,600	85,400	1,370	15
Moisture in flue gas	4,540	4,640	3,730	4,300	499	1
Particulates	0.222	0.222	0.205	0.216	0.01	<1
Total output	554,659	559,229	578,753	564,214	12,797	
Output/Input	0.97	0.96	1.003	0.98		
Average operating temperature in combustorF°	1750	1725	1725			

* Average
† Standard deviation

standard statistical methods. The confidence assigned to the accuracy of the estimate of the mean was determined by use of the Student test. Given three observations and wishing to establish a 90 percent confidence level in the estimation of the true mean, it can be stated that the minimum range that can be established for the true mean is the reported average value plus or minus 1.7 times the reported standard deviation.

TABLE 3. WATER MASS RATES
lb/hr

Item	Test Number 1	2	3	$\bar{X}$*	S†	% total
Input						
Sludge	12,858	15,252	11,539	13,216	1,882	3
Wood	5,487	5,759	4,564	5,270	626	1
Scrubber influent	449,280	449,280	473,242	457,267	13,834	96
Atomizing steam	1,000	1,000	1,000	1,000	-0-	<1
Humidity in combustion air	917	1,018	777	904	121	<1
Combustion of H_2 in fuel	534	593	453	527	70	<1
Total water input	470,076	472,902	491,575	478,184	11,682	
Output						
Flue gas moisture at stack	4,540	4,640	3,730	4,300	499	1
Scrubber discharge	374,400	384,384	335,962	364,915	25,566	76
Gas moisture + discharge	378,940	389,024	339,692	369,219	26,063	--
Scrubber overflow (input - exit gas moisture - discharge)	91,136	83,878	151,883	108,966	37,344	23

* Average
† Standard Deviation

SUMMARY OF OPERATING PROBLEMS

A number of design and operating problems have been encountered with the incineration-energy recovery system by plant operation personnel. The major problem areas include the sludge feed and ash handling systems and slagging. Of these, conversion of the ash handling system from a wet to a dry system was the most expensive and time consuming to date. Complete solutions have not been found in all cases, but progress is being made.

More extensive difficulties have surrounded the solid waste processing system and included explosions, plugging, lack of access to various process areas for repair and maintenance and spillage around transfer points. These

matters will not be discussed here since system modifications to correct these difficulties are still underway.** All of these problems are described in detail in a document prepared by the operating personnel of WLSSD.

TABLE 4. ASH MASS RATES
lb/hr

Item	Test Number 1	2	3	$\bar{X}$*	S†	% Total
Input						
Sludge	704	810	626	713	92	55
Wood	212	240	162	205	39	16
Sand	42	42	42	42	-0-	3
Scrubber influent	377	346	322	348	28	27
Total input	1,335	1,438	1,152	1,308	145	
Output						
Fly ash	683	627	578	636	53	45
Scrubber discharge	689	915	504	703	206	50
Scrubber overflow	75	65	105	82	21	6
Stack particulate	0.222	0.222	0.205	0.216	0.01	<1
Total output	1,447	1,607	1,187	1,414	212	
Output/input	1.08	1.12	1.03	1.08	0.05	

* Average
† Standard Deviation

SUMMARY OF PARTICULATE EMISSIONS

The particulate matter emitted from the WLSSD incineration system was collected primarily to permit determination of the metals content. The mass rates, however, can be compared with the Federal and State regulations and compliance tests performed in January 1984 to establish the reliability of the data. This comparison is presented in Table 5.

** Baker, G. and Habhegger, D., "Western Lake Superior Sanitary District - Codisposal Facility," September 20, 1982.

TABLE 5. PARTICULATE EMISSIONS RATES

Pollutant	Federal standard*	Compliance test†	This study§
Particulate	0.65 g/kg dry sludge feed**	0.247 g/kg	0.09 g/kg
Beryllium	10 g/24 hr	††	††
Mercury	3200 g/24 hr	††	††

* Applicable to sewage sludge incinerators
† Compliance test conducted by Interpoll on January 31, 1984
§ Not a compliance test
** State standard
†† None reported

As can be seen, the emission rates for this test and the compliance test are well within the Federal and State standards for particulates.

Conclusions

To help evaluate the fate of the metal in the system, the incineration process is explained in the following sentences. Flue gas from the fluidize-bed combustors passes through hot gas cyclones to effect fly ash removal. The hot flue gas (approximately 1600°F) then enters a waste heat boiler where energy is recovered to produce steam. Additional fly ash is collected from the boiler and deposited in the same hopper as that collected from the cyclones. The temperature of the flue gas is reduced to approximately 450°F before it passes through the venturi scrubbers and to 80° to 100°F as it passes through the secondary scrubber. The induced-draft fan imparts energy to the gas with a resultant increase temperature to 125°F and a heat exchanger further increases the gas temperature to approximately 220°F prior to discharge out of the stack.

By virtue of the integral energy recovery operation and subsequent changes to which the flue gas is subjected, this system cannot be directly compared to typical incineration/scrubber installations.

As mentioned previously, all of the elements found in the materials entering the system could not be accounted for in the output. This may be due in part to the gross measuring techniques employed or the result of the vaporization of certain elements through the process. In view of this fact, from Table 6, it can be seen that in a majority of cases, 50 percent or more of the input elements were removed in the fly ash. As would be expected the sulfur content of the fly ash was low; on the order 8 percent. However, the scrubber effects removal of approximately 49 percent of the system's sulfur

TABLE 6. ELEMENTAL COMPOSITION (PERCENT) OF OUTPUT STREAMS TO TOTAL INPUT

	Fly ash / Σ inputs	Net scrubber / Σ inputs	Particulates / Σ inputs	S outputs / Σ inputs
Ca	32.55	16.0	---*	48.6
Cu	82.57	2.79	---	82.9
P	24.36	---	<0.01	24.4
K	99.26	0.19	0.02	101.5
Ti	14.96	---	<0.01	15.1
Fe	90.09	1.78	<0.01	91.8
S	8.05	48.91	0.01	57.3
Mg	58.83	11.26	---	70.1
Na	62.80	17.63	---	83.1
Zn	56.04	.92	---	57.0
Ba	49.79	4.33	<0.01	54.1
Mn	59.88	0.90	<0.01	68.8
Cu	52.56	4.48	---	57.2
Pb	---	---	---	---
Sn	52.00	1023.	<0.01	62.6
Cr	93.3	---	---	93.3
V	48.08	---	---	48.1
Ni	63.1	---	0.04	63.1
Co	28.4	---	---	28.4
Si	1528.0	<0.01	5.01	6080.0
Mo	12.1	---	---	12.1
B	1508	---	---	1510.
Be	---	---	---	---
Cd	---	---	---	---

* Dashes indicate that the concentration of the reported element was below the analytical detection limit in one, two, or all three of the samples analyzed.

input. As can be seen, other elements were removed in the scrubber, but to a lesser extent. The stack emissions, when compared to the total input, appear insignificant.

Table 7 presents the average elemental composition (percent) of the major inputs and output constituents. For reference, a column showing the average composition of municipal wastewater sludge for 16 cities developed by Furr et al.,† is also presented. It can be observed that for a majority of the elements examined, the WLSSD sludge contained a much lower percentage of each element. This coupled with the inconsistencies observed in being able to account for the outputs in terms of inputs, tends to indicate that no clear conclusions regarding enrichment can be drawn in this case.

The net scrubber discharge from Table 1 indicates the quantities of metals picked up by the scrubbing solution from the gas stream. These constituents are either in dissolved or inparticulate form and are returned to the head end of the treatment plant. For example, examining the mass of zinc returned to the wastewater treatment plant, 14.6 gr/hr, it can be seen that the scrubber water would increase the zinc loading to the treatment plant by 0.35 kg/day. Current zinc influent loadings are on the order of 20 to 25 kg/day in the approximately 43 million gal/day treatment plant influent. In addition, since the scrubber water and the treatment plant water are neutral to acidic in nature, it is likely that a significant amount of the zinc would be or would remain in dissolved form and would ultimately be discharged with the treatment plant effluent. Thus, under these operating conditions, it is unlikely that zinc or other metals with similar solubility characteristics would accumulate in the treatment plant sludge, subsequently recycled to the incinerator, and then be returned to the treatment plant via the scrubber water in sufficient quantities to be detrimental to the biomass.

† Furr, A. K.; Lawrence, A. W.; Tong, S. S. C.; Grandolfo, M. S.; Hofstader, R. A.; Bache, C. A.; Gutenmann, W. H.; Lisk, D. J.; Environ. Sci. Technol., 1976, 10,683.

TABLE 7. AVERAGE ELEMENTAL COMPOSITION (PERCENT) OF MAJOR PROCESS STREAMS

	Sludge filter cake at 84% moisture		Wood chips		Fly ash		Particulate emissions		Average content 16 cities†
	Average	S*	Average	S	Average	S	Average	S	
Al	0.441	3.62E-02	0.006	1.65E-03	9.450	3.16E-01	---§	---	1.83
Ca	0.304	2.12E-02	0.717	2.62E-02	7.320	5.25E-01	---	---	3.62
P	0.200	2.59E-02	0.022	5.09E-03	1.340	1.58E-01	0.968	4.79E-01	1.56
Ti	0.173	3.06E-02	0.001	4.10E-04	0.404	2.87E-01	0.0180	1.43E-01	0.23
S	0.133	1.15E-02	0.026	4.26E-03	0.310	7.84E-02	1.607	3.63E-01	NR**
Fe	0.091	6.83E-02	0.001	5.29E-03	3.470	4.64E-01	---	---	3.06
K	0.100	1.82E-02	0.105	1.96E-02	4.720	7.95E-01	2.232	1.56E-00	1.22
Mg	0.086	8.90E-03	0.044	1.91E-03	1.870	6.35E-02	---	---	0.60
Na	0.042	3.80E-03	0.014	2.10E-02	0.941	6.59E-02	---	---	0.44
Zn	0.018	6.00E-04	0.006	1.00E-04	0.297	5.20E-03	---	---	0.21
Ba	0.007	1.15E-03	0.003	1.70E-04	0.124	5.51E-03	0.039	1.80E-02	0.06
Mn	0.005	1.06E-03	0.002	1.31E-03	0.110	1.00E-02	0.015	4.00E-03	0.019
Cu	0.003	3.70E-04	<0.001	1.50E-04	0.039	4.90E-03	---	---	0.13
Pb	0.002	1.00E-03	---	---	---	---	---	---	0.18
Sn	0.001	4.00E-05	0.001	7.00E-05	0.024	1.21E-03	0.004	3.00E-03	NR
Cr	<0.001	1.00E-04	---	---	0.014	1.57E-03	---	---	0.14
V	<0.001	3.00E-04	---	---	0.007	1.90E-04	---	---	0.004
Ni	<0.001	6.00E-05	---	---	0.008	1.34E-03	---	---	NR
Co	<0.001	1.00E-04	---	---	0.003	2.60E-04	---	---	0.001
Si	<0.001	1.50E-04	---	---	0.134	1.58E-03	1.28	5.89E-01	NR
Mo	<0.001	6.00E-04	---	---	<0.001	9.00E-05	---	---	NR
Be	---	---	---	---	---	---	---	---	NR

* Standard deviation

† Furr, A. K.; Lawrence, A. W.; Tong, S. S. C.; Grandolfo, M. S.; Hofstader, R. A.; Bache, C. A.; Gutenmann, W. H.; Lisk, D. J.; Environ. Sci. Technol., 1976, 10,683

§ Dashes indicate that the concentration of the reported element was below the analytical detection limit in one, two, or all three of the samples analyzed

** Not reported

SECTION 3

TEST PROCEDURES AND PLANT DESCRIPTION

OVERVIEW

Representative samples of each of the seven major process streams were acquired over a 6-hr test period during 3 days of normal incinerator operations. Samples of each process stream were composited to provide representative daily samples for metal analyses by Inductively Coupled Argon Plasma Emission Vacuum Spectroscopy (ICPES). In addition, the mass flow rate of each of the seven process streams was measured or calculated.

Figure 2 illustrates the system schematic and sampling locations. Descriptions of each process stream and specific sampling approaches are presented in the following paragraphs.

SEWAGE SLUDGE FILTER CAKE

Thickened sewage sludge containing approximately 8 percent solids is pumped either directly from the wastewater processing line or from sludge holding tanks and is mixed with dewatering polymers prior to being pumped to the belt presses. The belt presses yield a dewatered sludge filter cake with approximately 16 percent solids. This filter cake is carried via a serpentine conveyor to a moyno pump which feeds the FBC. The filter cake enters the FBC through the top of the reactor via a specially designed feed nozzle and is dispersed within the reactor by atomizing steam.

Figure 3 illustrates the mass flows in and out of the belt press. The flow rates of the thickened sludge, polymer, and spray wash are continuously measured by existing instrumentation, but the filter cake and filtrate flow rates are not measured. To accurately determine the mass of filter cake being fed to the reactor, it was necessary to establish a solids mass balance around the belt press system in order to solve for the actual wet output flow rates using the known solids concentrations.

Figure 3 defines the known and calculated parameters and derives the system balance equations for sludge flow rate. Hourly samples were taken of each input and output stream of the belt press and composited for each day of testing. Daily composites were analyzed for total solids. Filter cake samples were further analyzed for fuel properties and metals concentrations.

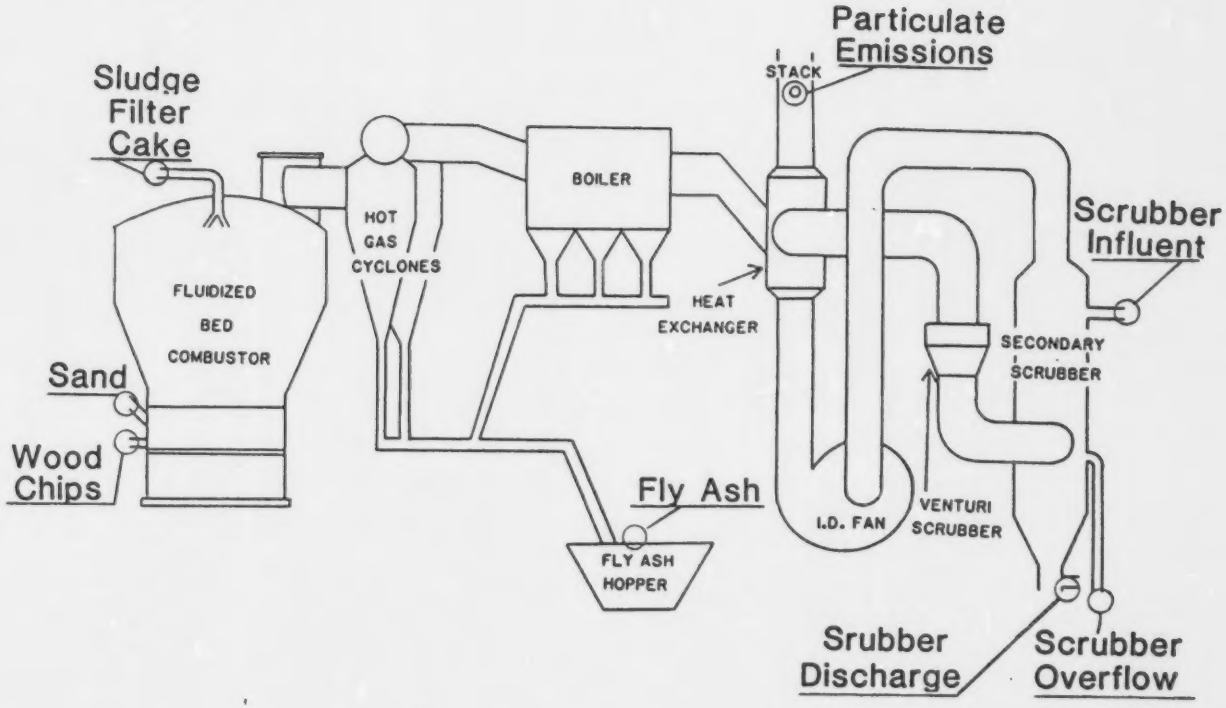
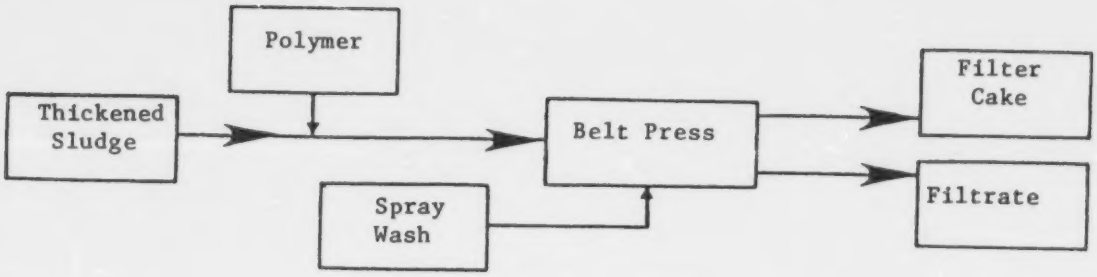


Figure 2. Metal analysis sampling locations.



Known (measured) Variables:

Sludge flow rate	(SFR)	(kg/hr)
Polymer flow rate	(PFR)	(kg/hr)
Spray wash flow rate	(WFR)	(kg/hr)
Sludge total solids	(STS)	(kg/kg)
Polymer total solids	(PTS)	(kg/kg)
Filter cake total solids	(CTS)	(kg/kg)
Filtrate total solids	(FTS)	(kg/kg)

Unknown Variables:

Filter cake flow rate	(CFR)	(kg/hr)
Filtrate flow rate	(FFR)	(kg/hr)

Continuity Equations:

$$SFR+PFR+WFR = CFR+FFR$$

$$(STS \times SFR)+(PTS \times PFR) = (CTS \times CFR)+(FTS \times FFR)$$

Eliminating FFR and Solving for CFR:

$$CFR = \frac{FTS(SFR+PFR+WFR)-STS(SFR)-PTS(PFR)}{(FTS-CTS)}$$

FFR can now be found from either the first or the second continuous equation.

Figure 3. Belt press mass balance.

WOOD CHIPS (FUEL)

The fluidized-bed sludge incineration system was designed to burn RDF as the auxiliary fuel. While modifications of the RDF processing system are being performed, woods chips are being used as the auxiliary fuel. Fortunately the consistent chemical properties and material handling characteristics of wood chips allowed the combustor operators an opportunity to optimize the operation of the FBC.

Upon receipt, the wood chips are stored in open piles or loaded directly into an atlas storage bin. When fired into the combustor, the wood is unloaded from the atlas and conveyed across a belt scale to a pneumatic feed system. The chips are then blown by the pneumatic system into the lower region of the fluidized bed.

Hourly belt scale readings provided data on the wood chip feed rate to the incinerator. Hourly samples of the wood chips were composited to form daily representative composite sample for analysis. The daily composite samples were analyzed for moisture content and processed in a laboratory blender prior to further analysis for residual moisture, ash, and metals content.

FLUIDIZED-BED SAND

The fluidized-bed reactor is operated with approximately 70 tons of sand in the bed. While burning wood chips, no sand is tapped directly out of the bed. However, the particle size of the sand is reduced by the abrasive action of particles colliding with one another in the fluidized state until some of the particles are small enough to be lofted and entrained by the combustion gases and carried downstream to the pollution control equipment. This sand, lost from the bed, is replenished every 2 or 3 days in 1-ton increments via a trip scale. Plant operating records were used to establish the average rate of replenishment of sand into the system. Historical data indicated an average sand depletion rate of 42 lb/hr. One representative sample of sand was obtained from the sand storage area and analyzed for metals.

FLY ASH

The flue gases and entrained particles leave the reactor exhaust and enter twin cyclones which remove the largest particles. The flue gases and remaining particles then pass through the waste-heat boiler. Some particles become deentrained within the boiler and fall into one of three hoppers below the boiler. The fly ash collected by the cyclones and the boiler hoppers is discharged through rotary valves to a screw conveyor which transports the ash to covered luggers (approximately 50 yd^3). These luggers are then trucked to a landfill for ultimate disposal.

The discharge rate of the combined cyclone and boiler fly ash was determined by weighing the combined fly ash collected during each 6-hr test

period. Combined fly ash was diverted to an empty preweighed lugger at the beginning of the test period, and the lugger was weighed again at the end of the test.

One representative sample was taken from the lugger at the end of the test period each day with a grain sampler (thief). Each of these three samples was subsequently analyzed for metals.

SCRUBBER SYSTEM

Figure 4 illustrates the major features of the scrubber system. Flue gases leaving the waste-heat boiler pass through a heat exchanger at the base of the stack, cooling the gases prior to their entering the venturi scrubber. After the variable throat venturi scrubber removes the majority of the remaining particulates, the flue gases pass upward through the secondary tray scrubber. After this final scrubbing, the flue gas is at its coolest temperature and saturated with water vapor. Flue gases are then drawn through the ID fan and warmed by the heat exchanger at the base of the stack before being released to the atmosphere.

In the scrubber, particles are removed from the flue gases by wastewater treatment plant effluent that enters the scrubber system at the top of the secondary tray scrubber. As water trickles over the trays, some water leaves the system through an upper overflow; the remainder accumulates in a reservoir at the base of the secondary scrubber. A portion of the water in this reservoir is pumped to the venturi scrubber that drains back into this reservoir. Another portion of the water is discharged directly from the reservoir and the scrubber system. A lower overflow maintains the reservoir level and prevents flooding of the venturi and the lower trays.

The volume of plant effluent entering the scrubber system is metered; the secondary scrubber reservoir water going to the venturi and to the scrubber discharge are monitored with rotameter flow gauges; and temperatures are monitored at various locations. Water leaving the system via the overflows cannot be measured. Water entering the system in the form of water vapor in the flue gas cannot be determined by direct measurement either, but complete assessment of water and solids entering and leaving the scrubber system can be made by performing a mass balance. Figure 5 is a simplified schematic indicating scrubber system inputs, outputs, and calculations for determining the scrubber overflow rate.

Figure 5 also lists all sources of moisture which contribute to the water vapor in the flue gases. The quantity of water which left the system was measured at the stack via EPA Methods 2 and 4. The difference between the flue gas water input and stack output water represents the mass of the water which condensed from the flue gas and exited the system via the scrubber overflow or discharge. Exit flue gas moisture was confirmed by noting the amount of moisture the gases are able to hold under saturated conditions at the temperature of the secondary scrubber outlet.

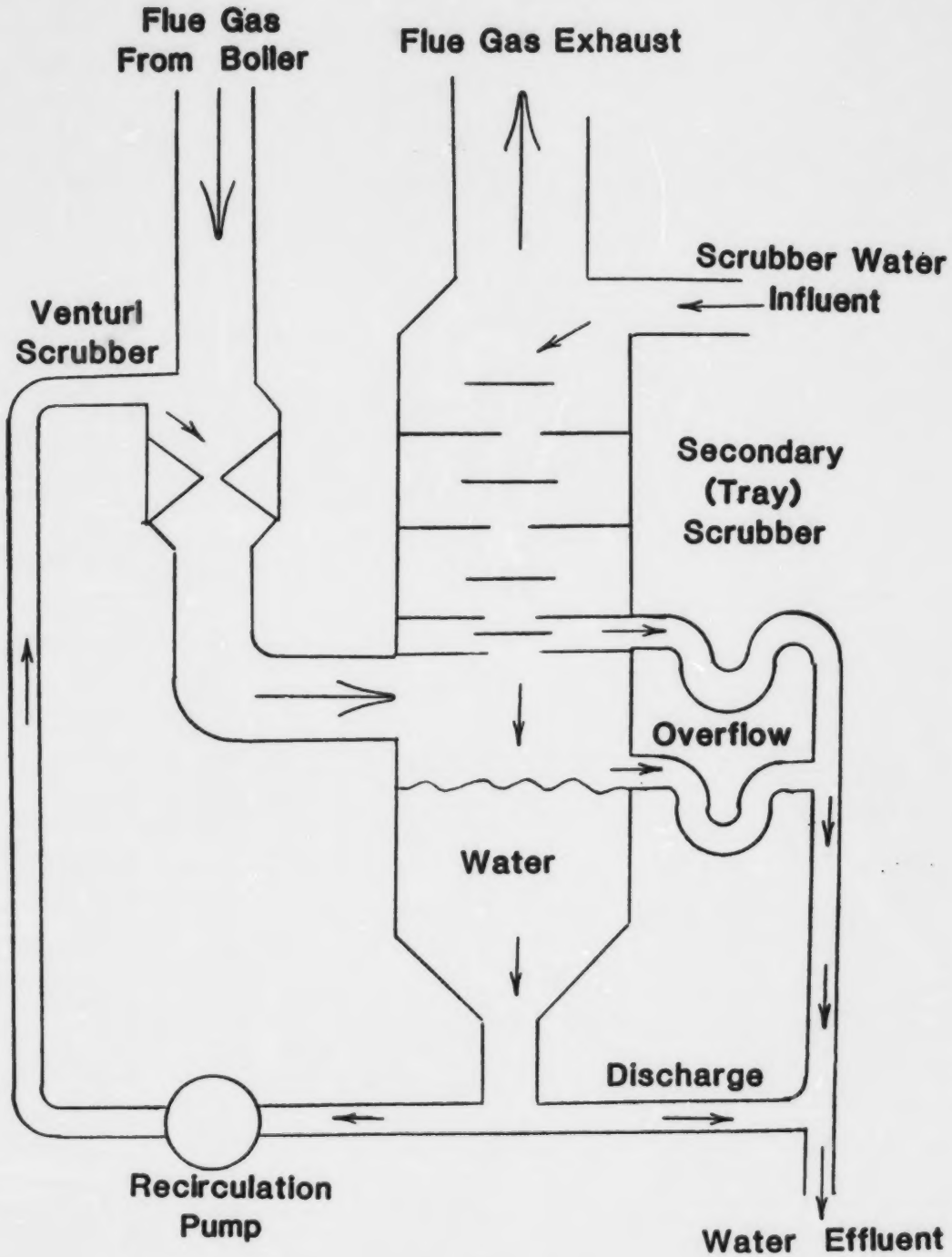
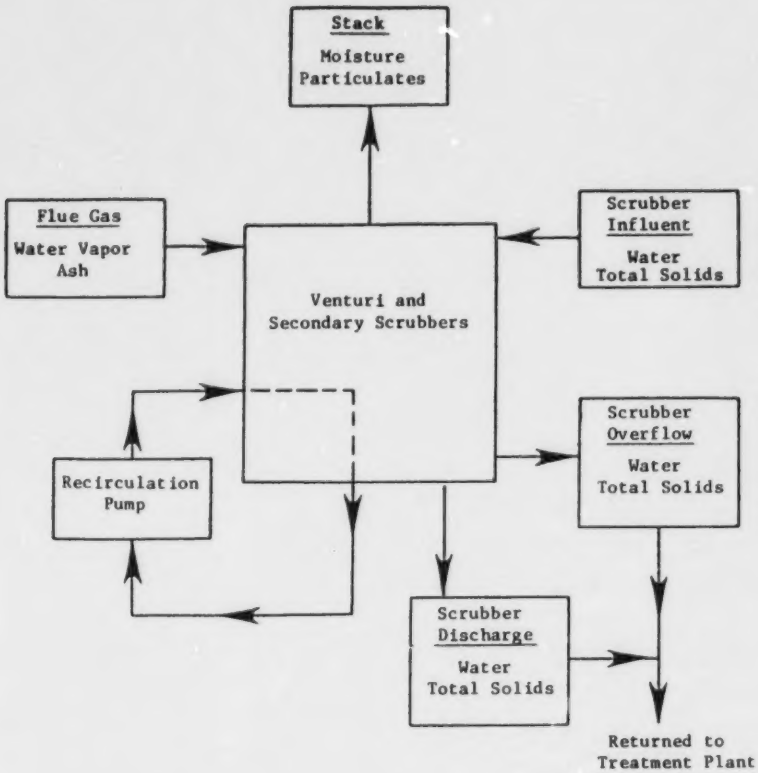


Figure 4. Scrubber system.



Water In = Water Out

Scrubber Influent Water

Flue Gas Water Vapor

- H_2O In Sludge
- H_2O In Wood
- H_2O In Combustion Air
- H_2O Due To Combustion Of H_2
- H_2O From Atomizing Steam

Stack Moisture

Scrubber Overflow

Scrubber Discharge

Scrubber Overflow = (Water In) Stack Moisture - Scrubber Discharge

Where the Water In = Scrubber Influent Water + Flue Gas Water Vapor

Figure 5. Scrubber mass balance.

Hourly samples of plant effluent (scrubber influent), scrubber overflows, and scrubber discharge were obtained during the test periods and composited into representative daily samples for total solids and metals analysis.

STACK EMISSIONS TESTS

After leaving the secondary scrubber, the water vapor saturated flue gases are drawn through the induced-draft fan and then pushed through the heat exchanger at the base of the stack. The heat exchanger warms the gases above their dew point allowing them to exit the stack with a minimal steam plume.

Sampling ports were installed on the stack inside the incineration building just below roof level to facilitate stack testing without weather related delays and complications. The new ports were approximately seven stack diameters (35 ft) downstream from the heat exchanger. An EPA Method 5 sampling train was operated isokinetically for 6 hours at one point of average velocity within the stack. Impingers 1 and 2 each contained 100 ml of distilled H_2O. EPA Methods 1 through 4 supplied other stack data which were required to calculate emission rates. The particulate filters and impinger solutions were subjected to metals analysis. It should be emphasized that this test was not intended to be a regulatory compliance test. The test objective was to collect a large representative sample of particles for metal analysis.

STACK SAMPLING QUALITY ASSURANCE

Quality assurance procedures appropriate to the metals analysis objectives were performed as follows. The Method 5 sample train glassware including pyrex-lined probe was acid cleaned prior to the test program. Reeve Angel AH-34 glass fiber filters were leached with hot distilled water to remove leachable metals prior to drying, desiccating, and determining tare weights. A methodology blank was performed on site the day prior to testing. The sample train was prepared as if for sampling, then the filter, acetone, probe wash, impinger contents and associated rinses were collected in appropriate sample containers and analyzed for metals content. The metals content of this blank was subsequently subtracted from metal content of individual test runs. All sample containers were new polyethylene and were acid rinsed with 20 percent HNO_3 and then triple rinsed with deionized H_2O.

Analytical performance was routinely monitored by analyzing standards, duplicates, and spiked samples. In addition, an EPA sludge reference sample and a NBS fly ash reference sample were analyzed and the results compared to accepted values. The results of these reference sample analyses are shown in the Appendix B.

SAMPLE DIGESTION

The samples of wood were dried at 105°C and processed in a laboratory blender. Wood and sludge samples were both ashed using a low temperature oxygen bomb technique. The prepared wood and sludge samples along with representative portions of all other analytical samples were then totally dissolved using a combination of hydrofluoric, nitric, hydrochloric, and perchloric acids in heated teflon beakers. The resulting solutions were neutralized, diluted, and analyzed.

The analysis was performed on Applied Research Laboratories Model 3400 B ICPES using EPA interim approved Method 200.7. This instrument is set up to analyzed 40 elements and is routinely capable of achieving the detection limits listed in Table 8.

TABLE 8. DETECTION LIMITS FOR ELEMENTAL DETERMINATIONS BY ICPES

Elements	Detection limit (µg/mL)
Aluminum	0.050
Antimony	0.032
Arsenic	0.057
Barium	0.0006
Beryllium	0.0005
Bismuth	0.049
Boron	0.009
Cadmium	0.008
Calcium	0.045
Chromium	0.001
Cobalt	0.006
Copper	0.001
Gold	0.048
Indium	0.055
Iron	0.008
Lead	0.084
Lithium	0.004
Magnesium	0.034
Manganese	0.001
Mercury	0.032
Molybdenum	0.002
Nickel	0.003
Phosphorous	0.18
Platinum	0.025
Potassium	0.042
Selenium	0.084
Silicon	0.016
Silver	0.002
Soldium	0.006
Strontium	0.0004
Sulfur	0.030
Tellurium	0.10
Thallium	0.091
Tin	0.12
Titanium	0.005
Tungsten	0.018
Uranium	0.064
Vanadium	0.003
Yttrium	0.002
Zinc	0.003

SECTION 4

RESULTS AND DISCUSSIONS

WOOD CHIPS

The mass rate of the wood chips entering the system was determined by taking hourly readings from a belt-scale totalizer meter. The belt scale was installed and calibrated just prior to the test sequence. During calibration it was noted that the installed belt was heavier than the belt specified for optimum sensitivity. The heavy belt was used during Day 1 and Day 2 tests. The proper weight belt was installed and calibrated prior to testing on Day 3. A splice in the light belt caused a high "noise" level in the readout rendering this data imprecise.

In general, the mass rate of wood chips as determined by the belt scale is a usable approximation of the actual mass rate. Other data was available to cross check the validity of this measurement from truck weights of incoming wood chip deliveries. These data indicate that the belt scale and truck scale disagreed by approximately 20 percent.

The mass rates of the wood chips entering the incinerator as determined by belt scale are presented in Table 9. The mass rates for water, dry solids, and ash were calculated from the percent composition of those repective components. The ultimate analysis data are literature values†† for mixed hardwood bark and were used along with sludge ultimate analyses to calculate the combustion air mass rate.

The concentration of metals in the wood chips burned during the 3 days of testing were determined as described in Section 3 and are reported in Table 10. Of the 40 elements analyzed, 14 were present in detectable quantities in all 3 samples. Average concentrations are presented for these 14 elements. In the instances where one or two of the samples reported nondetectable levels, those findings were not averaged. The risk of misinterpreting or misusing the average of detected concentrations and nondetected values far outweights their utility. The raw data are presented for the reader interested in evaluating concentrations and mass rates of inconsistently detectable elements.

---

†† Babcock and Wilcox, Steam/Its Generation and Use, 161 East 42nd Street, N.Y., N.Y. 10017, 1975, p. 5-23.

TABLE 9. WOOD CHIP COMPOSITION AND MASS RATE

Component	Basis	Units	Test Number 1	2	3	$\bar{X}$*	S†
Solids	wet	percent	58.9	58.1	57.7	58.2	0.6
Water	wet	percent	41.1	41.9	42.3	41.8	0.6
Ash	wet	percent				1.82	
Ash	dry	percent	2.7	3.0	2.6	2.77	.21
Carbon	wet	percent				30.3	
Carbon	dry	percent	---	---	---	51.7	
Hydrogen	wet	percent				3.22	
Hydrogen	dry	percent	---	---	---	5.5	
Oxygen	wet	percent				23.15	
Oxygen	dry	percent	---	---	---	39.5	
Nitrogen	wet	percent				.12	
Nitrogen	dry	percent	---	---	---	0.2	
Sulfur	wet	percent				.06	
Sulfur	dry	percent	---	---	---	0.1	
Mass Rates							
Total		lb/hr	13,400	13,700	10,800	12,600	1,600
Water		lb/hr	5,490	5,760	4,560	5,270	626
Solids		lb/hr	7,860	7,990	6,220	7,360	983
		lb/hr	212	240	162	205	39.5

* Average or literature value

† Standard deviation

When tested at the 95 percent confidence level, Day 2 has higher concentrations of several elements relative to Day 1 and Day 3. There is no known cause for these elevated values. It might be assumed that they are due to contamination of the wood chips. This contamination could have been introduced into the wood anywhere between the forest and the laboratory. The values reported for wood chips should be used with this observation in mind.

TABLE 10. METALS CONCENTRATIONS IN WOOD CHIPS
(µg/g dry solids)

Elements	Test Number 1	2	3	$\bar{X}$*	S†
Ag	<.35	<6.5	<.28	---	---
Al	120	110	68	9.93E01	2.76E01
As	<10	<2.7	<8.0	---	---
Au	<3	<3	<3	---	---
B	<1.6	24	<1.3	---	---
Ba	56	60	53	5.63E01	3.51E00
Be	<.085	0.20	<.067	---	---
Bi	<5	<5	<5	---	---
Ca	12,000	13,000	12,000	1.23E04	5.77E02
Cd	<.35	<.31	<.28	---	---
Co	<1.1	2.3	<.84	---	---
Cr	<.18	46	<.14	---	---
Cu	1.0	6.0	2.8	3.27E00	2.53E00
Fe	270	110	130	1.70E02	8.72E01
Hg	<3	<3	<3	---	---
In	<5	<5	<5	---	---
K	1,500	2,200	1,800	1.83E03	3.51E02
Li	<.076	280	<.060	---	---
Mg	780	770	770	7.73E02	5.77E00
Mn	41	46	42	4.30E01	2.65E00
Mo	<.35	3.9	<.28	---	---
Na	20	660	37	2.39E02	3.65E02
Ni	<.53	4.0	1.3	---	---
P	320	490	340	3.83E02	9.29E01
Pb	<15	24	<12	---	---
Pt	<3	<3	<3	---	---
S	410	540	400	4.50E02	7.81E01
Sb	<.57	<1	<4.5	---	---
Se	<15	<5	<12	---	---
Si	<2.8	8.3	<2.3	---	---
Sn	<12	<12	<12	---	---
Sr	18	17	16	1.70E01	1.00E00
Te	<10	<10	<10	---	---
Ti	16	20	6.2	1.31E01	6.90E00
Tl	<16	<14	<13	---	---
U	<10	<6	<6	---	---
V	<.53	9.2	<.42	---	---
W	<3	<3	<3	---	---
Y	<.2	<.2	<.2	---	---
Zn	95	98	100	9.77E01	2.52E00

* Average
† Standard deviation

The mass rates of detected elements introduced into the system via the wood chip stream were calculated by multiplying the measured concentration by the mass rate of the wood chips as determined by belt-scale reading corrected to a dry basis. The daily mass rates, average values, and standard deviations are presented in Table 11.

TABLE 11. WOOD CHIP METAL MASS RATE (g/hr)

Elements	Test Number 1	2	3	$\bar{X}$*	S†
Ca	4.30E04	4.72E04	3.40E04	4.14E04	6.76E03
K	5.37E03	7.99E03	5.09E03	6.15E03	1.60E03
Mg	2.79E03	2.80E03	2.18E03	2.59E03	3.55E02
S	1.47E03	1.96E03	1.13E03	1.52E03	4.17E02
P	1.15E03	1.78E03	9.62E02	1.30E03	4.28E02
Na	7.16E01	2.40E03	1.05E02	8.57E02	1.33E03
Fe	9.67E02	3.99E02	3.68E02	5.78E02	3.37E02
Al	4.30E02	3.99E02	1.92E02	3.40E02	1.29E02
Zn	3.40E02	3.56E02	2.83E02	3.26E02	3.83E01
Ba	2.00E02	2.18E02	1.50E02	1.89E02	3.52E01
Mn	1.47E02	1.67E02	1.19E02	1.44E02	2.42E01
Sr	6.44E01	6.17E01	4.53E01	5.71E01	1.04E01
Ti	5.73E01	7.26E01	1.75E01	4.91E01	2.84E01
Cu	3.58E00	2.18E01	7.92E00	1.11E01	9.51E00

* Average
† Standard deviation

SLUDGE FILTER CAKE

Since only the flow rates of thickened sludge, polymer and spray wash are continuously monitored, it was necessary to establish a solids-mass balance around the belt press systems to accurately determine the mass of filter cake being fed to the reactor. The sludge cake feed rate for the combustor can be calculated by the formula described in Section 3. Data used in the calculation and the results are presented in Table 12.

It should be noted that the total solids content of the filter press filterate as presented in Table 12, agreed favorably with routine monitoring data acquired simultaneously by WLSSD personnel. In addition, the resulting average sludge filter cake composition using routine WLSSD monitoring data was within 2 percent of that reported in Table 13.

The concentrations of metals in the filter cake are shown in Table 14, and the mass emission rate of metals with sludge cake is shown in Table 15.

TABLE 12. BELT PRESS DATA

Test no.	Test Number 1	2	3	$\bar{X}$*	St
SFR (kg/hr)	18,000	17,800	17,700	17,800	153
PFR (kg/hr)	4,790	5,390	4,790	4,990	346
WFR (kg/hr)	8,620	8,620	8,620	8,620	0
STS (kg/kg)	.0821	.0835	.0722	.0793	.0062
PTS (kg/kg)	.001	.001	.001	.001	0
CTS (kg/kg)	.163	.158	.148	.156	.0076
FTS (kg/kg)	.0143	.0080	.0150	.0124	.0039
CFR (kg/hr)	6,980	8,230	6,160	7,120	1,040

* Average
† Standard deviation

SFR = Thickened sludge flow rate
PRF = Polymer flow rate
WFR = Spray wash flow rate
STS = Sludge total solids
PTS = Polymer total solids
CTS = Filter cake total solids
FTS = Filtrate total solids
CFR = Filter cake flow rate

SAND

The mass rate of sand into the system was estimated to be 42 lb/hr (1000 lb/day) from applicable historical sand replenishment data. Concentrations of metals in one sample of sand are presented in Table 16. The calculated mass rates of the detectable elements are presented in Table 17.

FLY ASH

The measurement of the mass rate of fly ash leaving the system is described in Section 3 and the results are as follows:

Test 1 = 683 lb/hr
Test 2 = 647 lb/hr
Test 3 = 578 lb/hr
$\bar{X}$ = 636 lb/hr
S = 53 lb/hr

The concentrations of metals in the fly ash are presented in Table 18, and the resulting metal mass rates are presented in Table 19.

TABLE 13. SLUDGE FILTER CAKE COMPOSITION

Composition	Reporting basis	Units	Test Number 1	2	3	$\bar{X}$*	St
Solids							
total	wet	percent	16.3	15.8	14.8	15.6	0.76
volatile	dry	percent	71.9	71.7	68.8	70.8	1.74
Water	wet	percent	83.7	84.2	85.2	84.4	0.76
Ash	wet	percent	4.6	4.5	4.6	4.6	0.08
Ash	dry	percent	28.1	28.3	31.2	29.2	1.74
Carbon	wet	percent				6.05§	
Carbon	dry	percent				38.76§	
Hydrogen	wet	percent				.79§	
Hydrogen	dry	percent				5.07§	
Oxygen	wet	percent				3.3 §	
Oxygen	dry	percent				21.18§	
Nitrogen	wet	percent				.05§	
Nitrogen	dry	percent				0.29§	
Sulfur	wet	percent				.15§	
Sulfur	dry	percent				0.96§	

* Average
† Standard deviation
§ WLSSD historical data

SCRUBBER

Figure 6 indicates the mass rates of the various streams entering and leaving the scrubber. As discussed in detail in Section 3, the scrubber overflow rate was determined by difference because it could not be measured directly. Water vapor entering the scrubber with the flue gas comes from sources listed in Table 20. Water leaving the system as water vapor in the flue gas was measured at the stack. The difference between flue gas moisture entering and leaving the system is the quantity of water which condensed as the flue gas was cooled in the scrubber. The flow rate of water leaving the scrubber via the scrubber discharge was determined by rotameter. The flow rate of plant water entering the scrubber was determined by a venturi meter.

TABLE 14. METAL CONCENTRATIONS IN SLUDGE FILTER CAKE
(µg/g)

	Test number				
	1	2	3	$\bar{X}$*	St
Cake moisture (%)	83.7	84.2	85.2	84.4	0.76
Elements					
Ag	<3.5	<1.0	<5.7	---	---
Al	4,000	4,500	4,700	4.40E03	3.61E02
As	<2.9	<2.0	<5.1	---	---
Au	<3	<3	<3	---	---
B	<.46	8.4	<.811	---	---
Ba	61	73	84	7.27E01	1.15E01
Be	0.047	0.17	0.065	9.40E-02	6.64E-02
Bi	<5	<5	<5	---	---
Ca	2,800	3,100	3,200	3.03E03	2.08E02
Cd	<.10	8.3	2.8	---	---
Co	3.2	5.1	4.1	4.13E00	9.50E-01
Cr	4.9	6.5	4.8	5.40E00	9.54E-01
Cu	24	30	31	2.83E01	3.79E00
Fe	1,200	1,300	1,400	1.30E03	1.00E02
Hg	<3	<3	<3	---	---
In	<5	<5	<5	---	000
K	930	1200	850	9.93E02	1.83E02
Li	<.022	<.028	<.039	---	---
Mg	760	900	920	8.60E02	8.72E01
Mn	42	50	63	5.17E01	1.06E01
Mo	0.78	2.8	1.2	1.59E00	1.07E00
Na	380	450	440	4.23E02	3.79E01
Ni	4.2	4.7	5.4	4.77E00	6.03E-01
P	1,700	2,200	2,100	2.00E03	2.65E02
Pb	8.7	28	23	1.99E01	1.00E01
Pt	<3	<3	<3	---	---
S	1,200	1,400	1,400	1.33E03	1.15E02
Sb	<1.6	<3	<2.9	---	---
Se	<5.1	<5	<7.7	---	---
Si	1.7	4.7	3.2	3.20E00	1.50E00
Sn	<12	<12	<17	---	---
Sr	9.3	9.7	10	9.67E00	3.51E-01
Te	<10	<10	<10	---	---
Ti	1,400	1,800	2,000	1.73E03	3.06E02
Tl	<4.6	<9.5	<8.2	---	---
U	<6	<6	<6	---	---
V	3.0	8.6	3.8	5.13E00	3.03E00
W	<3	<3	<3	---	---
Y	<.2	<.2	<.2	---	---
Zn	180	170	180	1.77E02	5.77E00

* Average
† Standard deviation

TABLE 15. SLUDGE METAL MASS RATE (g/hr)

Elements	Test Number 1	2	3	$\bar{X}$*	S†
Al	2.79E04	3.70E04	2.90E04	3.13E04	4.99E03
Ca	1.95E04	2.55E04	1.97E04	2.16E04	3.40E03
P	1.19E04	1.81E04	1.29E04	1.43E04	3.33E03
Ti	9.77E03	1.48E04	1.23E04	1.23E04	2.52E03
S	8.38E03	1.15E04	8.62E03	9.51E03	1.75E03
Fe	8.38E03	1.07E03	8.62E03	9.23E03	1.27E03
K	6.49E03	9.88E03	5.24E03	7.20E03	2.40E03
Mg	5.30E03	7.41E03	5.67E03	6.13E03	1.12E03
Na	2.65E03	3.70E03	2.71E03	3.02E03	5.92E02
Zn	1.26E03	1.40E03	1.11E03	1.26E03	1.45E02
Ba	4.26E02	6.01E02	5.17E02	5.15E02	8.75E01
Mn	2.93E02	4.12E02	3.88E02	3.64E02	6.27E01
Cu	1.68E02	2.47E02	1.91E02	2.02E02	4.08E01
Pb	6.07E01	2.30E02	1.42E02	1.44E02	8.49E01
Sr	6.49E01	7.98E01	6.16E01	6.88E01	9.71E00
Cr	3.42E01	5.35E01	2.96E01	3.91E01	1.27E01
V	2.09E01	7.08E01	2.34E01	3.84E01	2.81E01
Ni	2.93E01	3.87E01	3.33E01	3.38E01	4.70E00
Co	2.23E01	4.20E01	2.53E01	2.99E01	1.06E01
Si	1.19E01	3.87E01	1.97E01	2.34E01	1.38E01
Mo	5.44E00	2.30E01	7.39E01	1.20E01	9.65E00
Be	3.28E-01	1.40E00	4.00E-01	7.09E-01	5.99E-01

* Average
† Standard deviation

The solids concentrations of the three scrubber water flows were determined and are reported in Table 21 along with flow rates and mass rates of the streams. Evaluation of the resulting ash balance (Figure 7) indicates 18 percent more solids leaving the system than entering. This apparent system imbalance is probably due to combined random measurement errors. It is highly improbable that any single input measure is in error to the extent required to account for the difference. The significance of this suspected measurement error are of little real consequence to the overall system balance. Solids from both scrubber overflow and discharge streams re-enter the wastewater treatment system and will eventually find their way back to the incineration system in the form of sludge solids or total solids in the scrubber influent. At the time of this test, the only solids leaving the WLSSD complex are stack particulates emitted to the atmosphere and fly ash which is landfilled.

TABLE 16. METALS CONCENTRATION IN SAND

Elements	Concentration µg/g
Ag	<1.30E+00
Al	5.60E+04
As	<8.00E+00
Au	<3.00E+00
B	2.00E+02
Ba	3.80E+02
Be	<9.50E-02
Bi	<5.00E+00
Ca	3.10E+04
Cd	1.00E+01
Co	4.40E+01
Cr	1.40E+02
Cu	7.70E+01
Fe	6.00E+04
Hg	<3.00E+00
In	<5.00E+00
K	1.50E+04
Li	<8.50E-02
Mg	1.80E-04
Mn	9.30E+02
Mo	9.80E+00
Na	1.40E+04
Ni	6.40E+01
P	6.50E+02
Pb	2.90E+01
Pt	<3.00E+00
S	4.80E+02
Sb	<3.00E+00
Se	<1.20E+01
Si	7.10E+01
Sn	<1.20E+00
Sr	1.40E+02
Te	<1.00E+01
Ti	8.10E+03
Tl	<9.00E+00
U	<6.00E+00
V	1.80E+02
W	<3.00E+00
Y	<2.00E-01
Zn	9.50E+01

TABLE 17. SAND, METAL MASS RATE
(g/hr)

Elements	Tests 1, 2, 3
Fe	1.15E03
Al	1.07E03
Ca	5.92E02
Mg	3.44E02
K	2.86E02
Na	2.67E02
Ti	1.55E02
Mn	1.78E01
P	1.24E01
S	9.16E00
Ba	7.25E00
B	3.82E00
V	3.44E00
Sr	2.67E00
Cr	2.67E00
Zn	1.81E00
Cu	1.47E00
Si	1.36E00
Ni	1.22E00
Co	8.40E-01
Pb	5.54E-01
Cd	1.91E-01
Mo	1.87E-01

Scrubber Particulate Removal Efficiency

As part of the data necessary for evaluating the fate of metals in the process, the research program measured the rates of flue gas particles and scrubber water effluent particles. Although it was not the intent when collecting such data, still it is possible to use these data to make an estimate of the efficiency of the scrubber. The scrubber particulate removal efficiency is estimated to be better than 99.94 percent based on the nonstandard test.

Scrubber Metal Concentrations

Tables 22, 23, and 24 report the results of the metal analysis of daily composite samples of scrubber influent, discharge, and overflow, respectively. The mass rates of metals in and out of the scrubber system are reported in Tables 25, 26, and 27.

TABLE 18. METALS CONCENTRATIONS IN FLY ASH (μg/g)

Elements	Test Number 1	2	3	$\bar{X}$*	St
Ag	<8.7	<7.8	<7.2	---	---
Al	98,000	92,000	93,000	9.43E04	3.21E03
As	<11	<7.3	<9.7	---	---
Au	<3	<3	<3	---	---
B	160	220	230	2.03E02	3.79E01
Ba	1,300	1,200	1,200	1.23E02	5.77E01
Be	<.093	<.061	<.082	---	---
Bi	<5	<5	<5	---	---
Ca	76,000	67,000	76,000	7.30E04	5.20E03
Cd	58	24	23	3.50E01	1.99E01
Co	28	31	33	3.07E01	2.52E00
Cr	140	120	150	1.37E02	1.53E01
Cu	450	370	360	3.93E02	4.93E01
Fe	32,000	40,000	32,000	3.47E04	4.62E03
Hg	<3	<3	<3	---	---
In	<5	<5	<5	---	---
K	47,000	55,000	39,000	4.70E04	8.00E03
Li	0.54	6.2	24	1.02E01	1.22E01
Mg	18,000	19,000	19,000	1.87E04	5.77E02
Mn	1,200	1,100	1,100	1.13E03	5.77E01
Mo	6.0	4.4	5.0	5.13E00	8.08E-01
Na	10,000	8,700	9,500	9.40E03	6.56E02
Ni	75	66	92	7.77E01	1.32E01
P	13,000	12,000	15,000	1.33E04	1.53E03
Pb	160	<9.5	<12.0	---	---
Pt	<3	<3	<3	---	---
S	3,500	2,200	3,600	3.10E03	7.81E02
Sb	<6.2	<4.1	<5.4	---	---
Se	<8	<4.8	<5.6	---	---
Si	1,200	1,300	1,500	1.33E03	1.53E02
Sn	<12	<12	<12	---	---
Sr	230	230	250	2.37E02	1.15E01
Te	<10	<10	<10	---	---
Ti	5,300	6,300	8,300	6.63E03	1.53E03
Tl	<9	<9	<6.5	---	---
U	<6	<6	<3	---	---
V	72	71	68	7.03E01	2.08E00
W	<3	<3	<3	---	---
Y	<.2	<.2	<.2	---	---
Zn	3,400	3,000	2,900	3.10E03	2.65E02

* Average
† Standard deviation

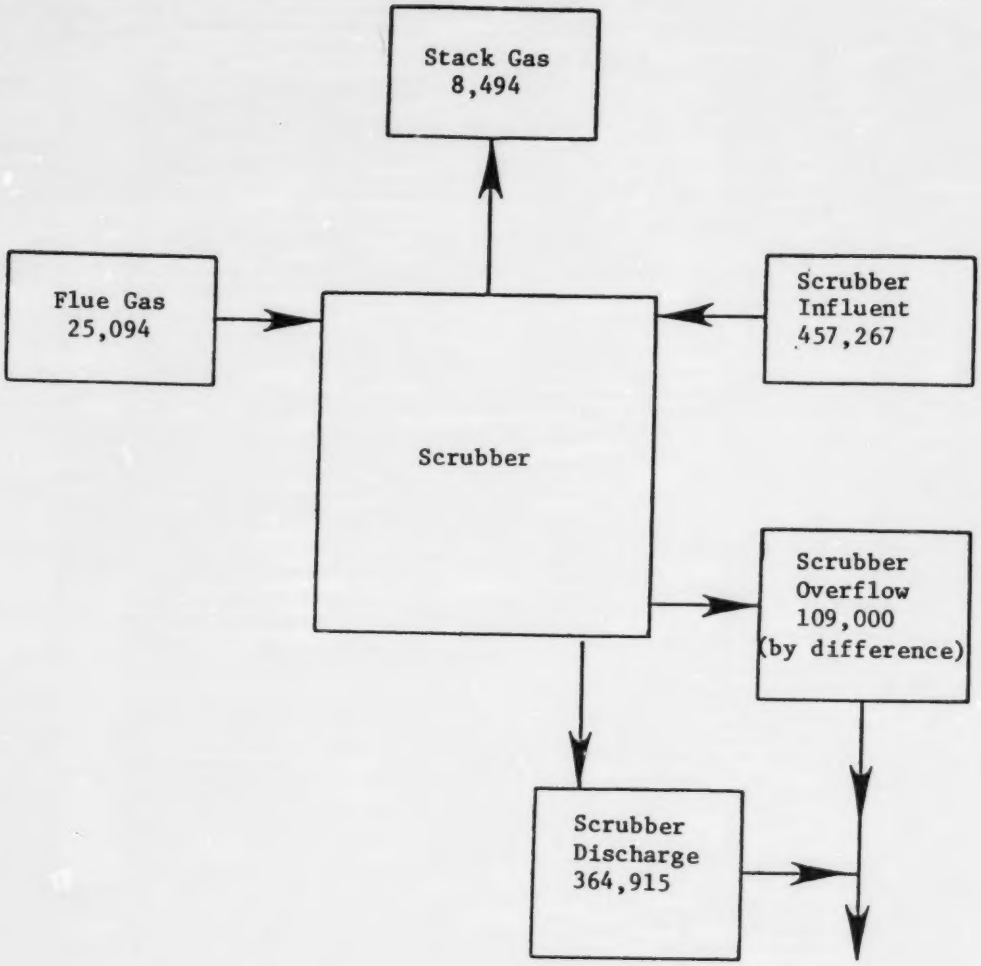
TABLE 19. FLY ASH METAL MASS RATE (g/hr)

Elements	Test Number 1	2	3	$\bar{X}$*	S†
Al	3.04E04	2.62E04	2.45E04	2.70E04	3.04E03
Ca	2.36E04	1.91E04	2.00E04	2.09E04	2.36E03
K	1.46E04	1.57E04	1.03E04	1.35E04	2.86E03
Fe	9.92E03	1.14E04	8.42E03	9.91E03	1.49E03
Mg	5.58E03	5.42E03	5.00E03	5.33E03	3.01E02
P	4.03E03	3.42E03	3.95E03	3.80E03	3.30E02
Na	3.10E03	2.48E03	2.50E03	2.69E03	3.53E02
Ti	1.64E03	1.80E03	2.18E02	1.87E03	2.78E02
Zn	1.05E03	8.55E02	7.63E02	8.91E02	1.49E02
S	1.09E03	6.27E02	9.47E02	8.86E02	2.35E02
Si	3.72E02	3.71E02	3.95E02	3.79E02	1.34E01
Ba	4.03E02	3.42E02	3.16E02	3.54E02	4.48E01
Mn	3.72E02	2.85E02	2.89E02	3.15E02	4.90E01
Cu	1.40E02	1.05E02	9.47E01	1.13E02	2.34E01
Sr	7.13E01	6.56E01	6.58E01	6.75E01	3.26E00
B	4.96E01	6.27E01	6.05E01	5.76E01	7.01E00
Cr	4.34E01	3.42E01	3.95E01	3.90E01	4.62E00
Ni	2.33E01	1.88E01	2.42E01	2.21E01	2.88E00
V	2.23E01	2.02E01	1.79E01	2.01E01	2.22E00
Cd	1.80E01	6.84E00	6.05E00	1.03E01	6.67E00
Co	8.68E00	8.84E00	8.68E00	8.73E00	8.98E-02
Li	1.67E-01	1.77E00	6.31E00	2.75E00	3.19E00
Mo	1.86E00	1.25E00	1.32E00	1.48E00	3.34E-01

* Average
† Standard deviation

Determination of Stack Mass Rate

As discussed in Section 3, stack sampling was performed to collect a large representative sample of stack particulates for subsequent metal analysis and to collect the data required to calculate stack flow rates. Table 28 presents data which were pertinent to calculation of the mass rates of dry gas, moisture, and particulates exiting the system through the stack. The resulting mass rates are presented at the bottom of the table. The calculation equations used were taken directly from the EPA Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III (EPA 600/4-77-0276).



Σ In = 482,361 Σ Out = 482,361

Figure 6. Scrubber water balance (lb/hr).

TABLE 20. FLUE GAS MOISTURE TO SCRUBBER

Source	Units	Test Number 1	2	3	$\bar{X}$*	St
Wood	lb/hr	5,490	5,760	4,560	5,270	626
Sludge	lb/hr	12,900	15,300	11,500	13,200	1,880
Combustion air/humidity	lb/hr	917	1,020	777	904	121
Combustion of H_2 in fuel	lb/hr	530	590	450	520	70
Atomizing steam	lb/hr	1,000	1,000	1,000	1,000	---
Total moisture input	lb/hr	20,800	23,600	18,300	20,900	2,650
Stack moisture	lb/hr	4,540	4,640	3,730	4,300	499
Moisture condensed in scrubber	lb/hr	16,300	19,000	14,600	16,600	2,210
	gal/min	33	38	29	33	4.5

* Average
† Standard deviation

Stack Metals Emissions

Tables 29 and 30 present laboratory data from the analysis of the stack particulate and the impinger condensate samples. The majority of the elements analyzed in these two samples were at nondetectable levels. Tables 31 and 32 present the mass emission rates of metals from the stack.

TABLE 21. SCRUBBER SOLIDS AND MASS RATES

Item	Units	Test Number 1	2	3	$\bar{X}$*	St
Scrubber influent						
flow rate	gal/min	900	900	948	916	27.7
mass rate	lb/hr	449,000	449,000	473,000	457,000	13,800
total solids	percent	.084	.077	.068	.076	.008
solids mass rate	lb/hr	377	346	322	348	27.9
Scrubber discharge						
flow rate	gal/min	750	770	673	731	51.2
mass rate	lb/hr	374,000	384,000	336,000	365,000	25,600
total solids	percent	.184	.238	.150	.191	.044
solids mass rate	lb/hr	689	915	504	703	206
Scrubber overflow (by difference)						
flow rate	gal/min	183	168	304	218	74.6
mass rate	lb/hr	93,300	84,000	152,000	109,000	37,300
total solids	percent	.082	.077	.069	.076	.007
solids mass rate	lb/hr	74.9	64.7	105	81.5	21.0

* Average
† Standard deviation

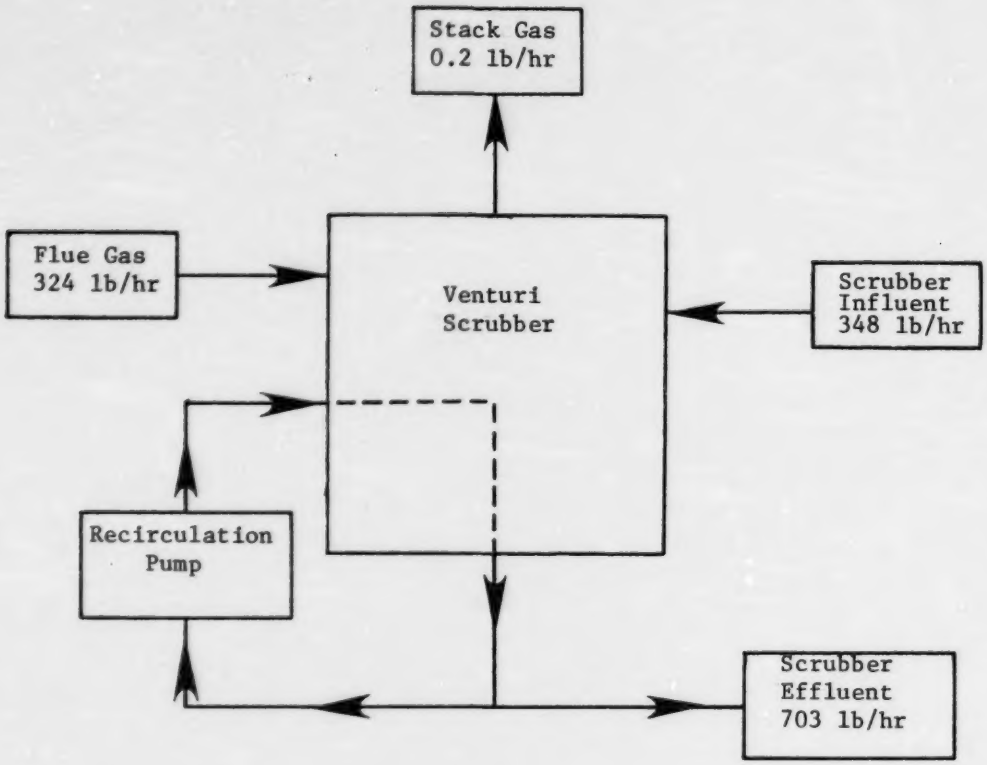
OPERATING PROBLEMS

To provide some insight into the operating and design difficulties associated with the incineration system, plant personnel prepared a description of the major problems encountered which are outlined below as well as solution where applicable.§

Sludge Feed System

The sludge feed system original designed to deliver sludge into the combustors used a series of belt conveyors which transported filter cake from the dewatering system to the top of the FBC's where the sludge was plowed onto the short cross-conveyors which in turn dumped the cake into openings and into the top of the FBC. The feed into the FBC was controlled by a slide

§ Baker, G., Habhegger, D., "Western Lake Superior Sanitary District-Codisposal Facility," September 20, 1982.



Σ In = 672 Σ Out = 785

Difference = +113 Out

= 18 Percent of Input

Figure 7. Scrubber ash balance (lb/hr).

TABLE 22. METAL CONCENTRATIONS IN SCRUBBER INFLUENT (µg/ml)

Elements	Test Number 1	2	3	$\bar{X}$*	St
Ag	<.002	<.002	<.002	---	---
Al	0.18	0.20	0.29	2.23E-01	5.86E02
As	<.057	<.057	<.057	---	---
Au	<.03	<.03	.03	---	---
B	<.009	<.009	.022	---	---
Ba	0.093	0.10	0.090	9.43E-02	5.13E-03
Be	<.0005	<.0005	<.0005	---	---
Bi	<.05	<.05	<.05	---	---
Ca	71	80	74	7.50E01	4.58E00
Cd	0.002	<.002	<.002	---	---
Co	<.006	<.006	<.006	---	---
Cr	<.001	<.001	<.001	---	---
Cu	<.001	<.001	<.001	---	---
Fe	1.1	0.86	0.64	8.67E-01	2.30E-01
Hg	<.03	<.03	<.03	---	---
In	<.05	<.05	<.05	---	---
K	5.7	5.7	5.8	5.73E00	5.77E-02
Li	<.0005	<.0005	<.0005	---	---
Mg	15	17	16	1.60E01	1.00E00
Mn	0.21	0.22	0.25	2.27E-01	2.08E-02
Mo	<.002	<.002	0.033	---	---
Na	190	190	170	1.83E02	1.15E01
Ni	<.003	<.003	<.003	---	---
P	<.18	<.18	0.27	---	---
Pb	<.084	<.084	<.084	---	---
Pt	<.03	<.03	<.03	---	---
S	23	23	21	2.23E01	1.15E00
Sb	<.032	<.032	<.035	---	---
Se	<.084	<.084	<.084	---	---
Si	7.9	8.7	8.4	8.33E00	4.04E-01
Sn	<.12	<.12	<.12	---	---
Sr	0.11	0.12	0.11	1.13E-01	5.77E-03
Te	<.10	<.10	<.10	---	---
Ti	<.005	<.005	<.005	---	---
Tl	<.091	<.091	<.091	---	---
U	<.06	<.06	<.06	---	---
V	<.003	<.003	<.003	---	---
W	<.03	<.03	<.03	---	---
Y	<.002	<.002	<.002	---	---
Zn	0.021	0.035	0.038	3.13E-02	9.07E-03

* Average

† Standard deviation

TABLE 23. METALS CONCENTRATIONS IN SCRUBBER DISCHARGE (μg/ml)

Elements	Test Number 1	2	3	$\bar{X}$*	S†
Ag	<.002	<.002	<.002	---	---
Al	0.95	0.70	0.40	6.83E-01	2.75E-01
As	<.057	<.057	<.057	---	---
Au	<.03	<.03	<.03	---	---
B	<.009	0.026	0.016	---	---
Ba	0.28	0.27	0.26	2.70E-01	1.00E-01
Be	<.0005	<.0005	<.0005	---	---
Bi	<.05	<.05	<.05	---	---
Ca	140	140	120	1.33E02	1.15E01
Cd	<.002	<.002	<.002	---	---
Co	<.006	<.006	<.006	---	---
Cr	<.001	0.003	<.001	---	---
Cu	0.071	0.083	0.015	5.63E-02	3.59E-02
Fe	1.3	0.92	0.63	9.50E-01	3.36E-01
Hg	<.03	<.03	<.03	---	---
In	<.05	<.05	<.05	---	---
K	7.6	8.1	5.0	6.90E00	1.66E00
Li	<.0005	<.0005	<.0005	---	---
Mg	22	22	20	2.13E01	1.15E00
Mn	0.51	0.47	0.42	4.67E-01	4.51E-02
Mo	<.002	0.013	<.002	---	---
Na	200	180	160	1.80E02	2.00E01
Ni	<.003	0.012	<.003	---	---
P	<.18	1.2	<.18	---	---
Pb	<.084	<.084	<.084	---	---
Pt	<.03	<.03	<.03	---	---
S	57	57	44	5.27E01	7.51E00
Sb	<.032	<.032	<.032	---	---
Se	<.084	<.084	<.084	---	---
Si	15	15	13	1.43E01	1.15E00
Sn	<.12	<.12	<.12	---	---
Sr	0.20	0.19	0.17	1.87E-01	1.53E-02
Te	<.10	<.10	<.10	---	---
Ti	0.17	0.19	0.007	1.22E-01	1.00E-01
Tl	<.091	<.091	<.091	---	---
U	<.06	<.06	<.06	---	---
V	<.003	<.003	<.003	---	---
W	<.03	<.03	<.03	---	---
Y	<.002	<.002	<.002	---	---
Zn	0.13	0.11	0.10	1.13E-01	1.53E-02

* Average
† Standard deviation

TABLE 24. METALS CONCENTRATIONS IN SCRUBBER OVERFLOW (µg/ml)

Elements	Test Number 1	2	3	$\bar{X}$*	S†
Ag	<.002	<.002	<.002	---	---
Al	0.52	0.39	0.47	4.60-01	6.56E-02
As	<.057	<.057	<.057	---	---
Au	<.03	<.03	<.03	---	---
B	<.009	<.009	0.070	---	---
Ba	0.11	0.11	0.11	1.10-01	0.00E00
Be	<.0005	<.0005	<.0005	---	---
Bi	<.05	<.05	<.05	---	---
Ca	75	75	74	7.47E01	5.77E-01
Cd	<.002	<.002	<.002	---	---
Co	<.006	<.006	<.006	---	---
Cr	<.001	<.001	<.001	---	---
Cu	<.001	<.001	<.001	---	---
Fe	5.0	6.7	2.7	4.80E00	2.01E00
Hg	<.03	<.03	<.03	---	---
In	<.05	<.05	<.05	---	---
K	6.1	5.5	5.9	5.83E00	3.06E-01
Li	<.0005	<.0005	<.0005	---	---
Mg	16	16	16	1.60E01	0.00E00
Mn	0.29	0.38	0.35	3.40E01	4.58E-02
Mo	<.002	<.002	<.002	---	---
Na	200	180	160	1.80E02	2.00E01
Ni	<.003	<.003	<.003	---	---
P	<.18	<.18	0.27	---	---
Pb	<.084	<.084	<.084	---	---
Pt	<.03	<.03	<.03	---	---
S	26	27	22	2.50E01	2.65E00
Sb	<.032	<.032	<.032	---	---
Se	<.084	<.084	<.084	---	---
Si	8.8	8.5	8.6	8.63E00	1.53E-01
Sn	<.12	<.12	<.12	---	---
Sr	0.12	0.11	0.11	1.13E01	1.13E-01
Te	<.10	<.10	<.10	---	---
Ti	<.005	<.005	0.017	---	---
Tl	<.091	<.091	<.091	---	---
U	<.06	<.06	<.06	---	---
V	<.003	<.003	<.003	---	---
W	<.03	<.03	<.03	---	---
Y	<.002	<.002	<.002	---	---
Zn	0.032	0.039	0.039	4.23E-02	1.23E-02

* Average
† Standard deviation

TABLE 25. SCRUBBER INFLUENT METAL MASS RATE (g/hr)

Elements	Test Number 1	2	3	$\bar{X}$*	S†
Na	3.88E04	3.88E04	3.66E04	3.80E04	1.28E03
Ca	1.45E04	1.63E04	1.59E04	1.56E04	9.55E02
S	4.69E03	4.69E03	4.52E03	4.63E03	9.81E01
Mg	3.06E03	3.47E03	3.44E03	3.32E03	2.29E02
Si	1.61E03	1.77E03	1.81E03	1.73E03	1.04E02
K	1.16E03	1.16E03	1.25E03	1.19E03	4.86E01
Fe	2.24E02	1.75E02	1.38E02	1.79E02	4.35E01
Mn	4.28E01	4.49E01	5.38E01	4.72E01	5.80E00
Al	3.67E01	4.08E01	6.24E01	4.66E01	1.38E01
Sr	2.24E01	2.45E01	2.37E01	2.35E01	1.03E00
Ba	1.90E01	2.04E01	1.94E01	1.96E01	7.40E-01
Zn	4.28E00	7.14E00	8.17E00	6.53E00	2.01E00

* Average
† Standard deviation

TABLE 26. SCRUBBER DISCHARGE METAL MASS RATE (g/hr)

Elements	Test Number 1	2	3	$\bar{X}$*	S†
Na	3.40E04	3.15E04	2.45E04	3.00E04	4.94E03
Ca	2.38E04	2.45E04	1.84E04	2.22E04	3.36E03
S	9.69E03	9.98E03	6.73E03	8.80E03	1.80E03
Mg	3.74E03	3.85E03	3.06E03	3.55E03	4.28E02
Si	2.55E03	2.63E03	1.99E03	2.39E03	3.48E02
K	1.29E03	1.42E03	7.65E02	1.16E03	3.46E02
Fe	2.21E02	1.61E02	9.64E01	1.59E02	6.23E01
Al	1.62E02	1.23E02	6.12E01	1.15E02	5.08E01
Mn	8.67E01	8.23E01	6.43E01	7.77E01	1.19E01
Ba	4.76E01	4.73E01	3.98E01	4.49E01	4.42E00
Sr	3.40E01	3.33E01	2.60E01	3.11E01	4.41E00
Ti	2.89E01	3.33E01	1.07E00	2.11E01	1.75E01
Zn	2.21E01	1.93E01	1.53E01	1.89E01	3.41E00
Cu	1.21E01	1.45E01	2.30E00	9.63E00	6.47E00

* Average
† Standard deviation

TABLE 27. SCRUBBER OVERFLOW METAL MASS RATE (g/hr)

Elements	Test Number 1	2	3	X*	S†
Na	8.28E03	6.86E03	1.10E04	8.73E03	2.13E03
Ca	3.11E03	2.86E03	5.11E03	3.69E03	1.23E03
S	1.08E03	1.03E03	1.52E03	1.21E03	2.69E02
Mg	6.62E02	6.10E02	1.10E03	7.92E02	2.71E02
Si	3.64E02	3.24E02	5.93E02	4.27E02	1.45E02
K	2.53E02	2.10E02	4.07E02	2.90E02	1.04E02
Fe	2.07E02	2.55E02	1.86E02	2.16E02	3.45E01
Al	2.15E01	1.49E01	3.24E01	2.29E01	8.87E00
Mn	1.20E01	1.45E01	2.42E01	1.69E01	6.42E00
Sr	4.97E00	4.19E00	7.59E00	5.58E00	1.78E00
Ba	4.55E00	4.19E00	7.59E00	5.45E00	1.87E00
Zn	1.32E00	1.49E00	3.86E00	2.22E00	1.42E00

* Average
† Standard deviation

gate, a motor driven cake breaker, and a counterweighted "flop gate." Since the FBR was at a negative pressure a majority of the time, the concept was, when the sludge was fed into the holes of the reactor, no combustion gases would escape. However a constant negative pressure could not be maintained and when the pressure became positive, fumes, smoke, and at times, fire blew out through the top of the FBC. In addition, large masses of sludge would fall into the combustor in slugs resulting in steam flashes and sudden combustion of sludge which created severe pressure excursions. It was suspected that there was incomplete combustion of the sludge and pyrolyzed gases were escaping without burning.

As a result, the sludge feed system was modified. A nozzle, which is a cone within a cone, was developed whereby the sludge was extruded into a thin sheet. A steam jet, located within the inner cone, cuts the sheet of sludge into pieces and disperses it across the bed area. A diagram of the nozzle is presented in Figure 8.

Several advantages have been gained from the nozzle such as: the sludge feeds evenly reducing pressure excursions, thereby, making the unit easier to control; the sludge is dispersed over the bed allowing it to burn completely; and finally the sludge is somewhat dried on the way to the bed which makes it burn faster.

Sludge is delivered to a hopper by a "Serpentex" conveyor from which it is pumped into a manifold connected to both FRCs. Ample air and water flush lines are provided to prevent plugging.

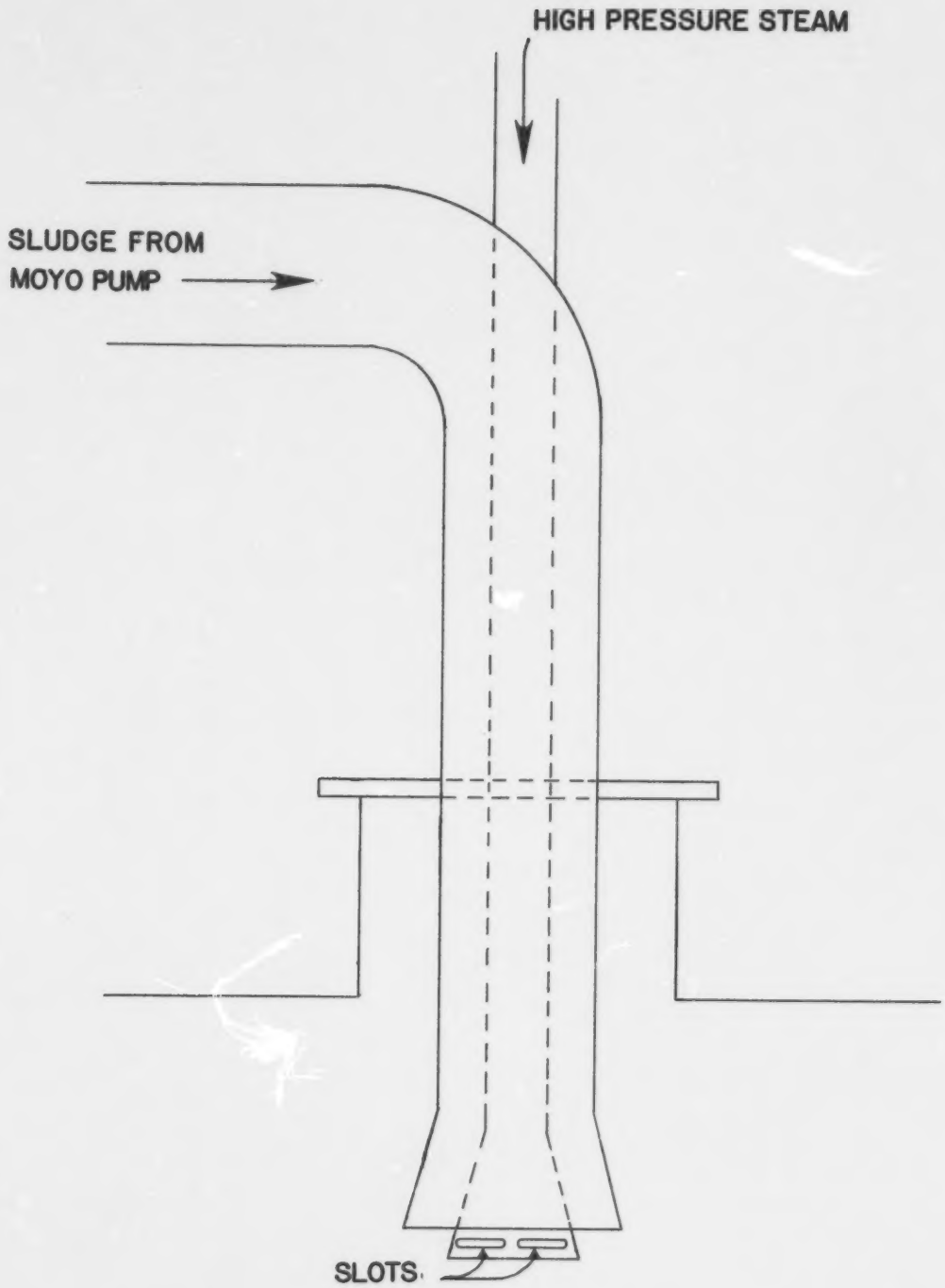


Figure 8. Sludge feed nozzle.

TABLE 28. STACK DATA AND MASS RATES

Item	Blank	Test Number 1	2	3
Sampling data				
Net particulate wt (g/test)	.0000	.0109	.0109	.0077
Impinger catch volume (ml/test)	202.5	604.9	618.5	432.7
Impinger catch net wt (g)	0.000	.0133	.0136	.0087
Total particulate collected (g)	0.000	.0242	.0245	.0164
Impinger catch/total particulate (ratio)		.55	.56	.53
Velocity (stack conditions)	ft/S	20.9	20.5	20.4
Flow rate	DSCFH	9.97×10^5	1.02×10^6	1.03×10^6
Mass rates				
Dry gas	lb/hr	8.39×10^4	8.57×10^4	8.66×10^4
Moisture	lb/hr	4.54×10^3	4.64×10^3	3.73×10^3
Particulates	lb/hr	0.222	0.222	0.205
	gram/hr	100.9	100.9	93.2

Ash Handling System

The original ash handling system was a wet system which integrated cyclone ash, boiler ash, excess bed materials, and scrubber ash. Each of these inputs have different physical characteristics which made co-treatment of the materials virtually impossible. For example, the bed material contains sand, rocks and metal of all kinds, and material collected in the wet scrubber was sub-micron in size.

TABLE 29. TOTAL METALS IN PROBE WASH PLUS PARTICULATE FILTER

Elements	Blank µg/blank	Test Number 1 µg/test	2 µg/test	3 µg/test
Ag	<.02	<.02	<.2	<.2
Al	18	10	100	12
As	<.6	<.6	<.6	<.6
Au	<.3	<.3	<.3	<.3
B	2.5	<.09	1.6	2.0
Ba	1.1	2.2	1.6	2.0
Be	<.005	<.005	<.005	<.005
Bi	<.5	<.5	<.5	<.5
Ca	350	290	260	300
Cd	0.3	0.67	0.16	1.3
Co	<.06	<.06	<.06	<.06
Cr	0.56	0.20	0.69	0.46
Cu	2.2	1.7	19	0.64
Fe	14	18	14	20
Hg	<.3	<.3	<.3	<.3
In	<.5	<.5	<.5	<.5
K	1.5	72	83	9.6
Li	<.005	<.005	<.005	<.005
Mg	71	54	51	57
Mn	<.01	1.0	0.44	0.75
Mo	<.02	<.02	0.05	0.07
Na	43	58	51	19
Ni	0.59	0.87	0.91	0.92
P	<1.8	16	19	25
Pb	<.84	<.8	0.93	<.8
Pt	<.3	<.3	<.3	<.3
S	12	59	53	32
Sb	<.3	<.3	<.03	<.3
Se	<.8	<.8	<.8	<.8
Si	14	60	32	34
Sn	<1.2	<1.2	<1.2	<1.2
Sr	0.22	0.36	0.24	0.34
Te	<1.0	<1.0	<1.0	1.0
Ti	2.9	6.4	4.3	8.4
Tl	<.9	<.9	<.9	<.9
U	<.6	<.6	<.6	<.6
V	<.03	<.03	0.07	0.19
W	<.3	<.3	<.3	<.3
Y	<.02	<.02	<.02	<.02
Zn	9.5	8.2	2.5	2.6

TABLE 30. METALS CONCENTRATION IN IMPINGER CATCH

Elements	Blank µg/ml	Test Number 1 µg/ml	2 µg/ml	3 µg/ml
Ag	<.002	0.005	<.002	<.002
Al	0.31	0.20	0.52	0.27
As	<.06	<.057	<.057	<.057
Au	<.03	<.03	<.03	<.03
B	<.009	<.009	<.009	<.009
Ba	0.023	0.022	0.018	0.020
Be	0.002	<.0005	<.0005	<.0005
Bi	<.05	<.05	<.03	<.05
Ca	0.10	<.045	<.045	<.045
Cd	<.002	0.019	<.002	<.002
Co	0.012	<.006	<.006	<.006
Cr	<.001	<.001	<.001	<.001
Cu	0.061	<.001	0.053	<.001
Fe	<.008	<.008	<.008	<.008
Hg	<.03	<.03	<.03	<.03
In	<.05	<.05	<.05	<.05
K	0.75	0.12	<.042	0.086
Li	< .0005	<.0005	<.0005	<.0005
Mg	0.11	<.034	<.034	<.034
Mn	<.001	<.001	<.001	<.001
Mo	0.029	0.005	<.002	<.002
Na	1.1	0.54	0.93	1.7
Ni	0.007	0.003	<.003	0.005
P	0.94	<.18	<.18	<.18
Pb	<.08	<.084	<.084	<.084
Pt	<.03	<.03	<.03	<.03
S	0.49	1.0	2.1	1.6
Sb	<.03	<.032	<.032	<.032
Se	<.084	<.084	<.084	<.084
Si	0.96	1.1	3.3	1.7
Sn	<.12	<.12	<.12	<.12
Sr	< .0005	<.0005	<.0005	<.0005
Te	<.10	<.10	<.10	<.10
Ti	0.015	<.005	<.005	<.005
Tl	<.091	<.091	<.091	<.091
U	<.06	<.06	<.06	<.06
V	0.05	0.008	<.003	0.004
W	<.03	<.03	<.03	<.03
Y	<.002	<.002	<.002	<.002
Zn	0.011	0.40	<.003	0.006

TABLE 31. PARTICULATE METAL MASS RATE (g/hr)

Elements	Test Number 1	2	3	$\bar{X}$*	St
K	2.94E00	3.32E00	4.61E-01	2.24E00	1.55E00
S	1.96E00	1.67E00	1.14E00	1.59E00	4.17E-01
Si	1.92E00	7.33E-01	1.14E00	1.26E00	6.03E-01
P	6.67E-01	7.73E-01	1.42E00	9.54E-01	4.09E-01
Ti	1.46E-01	5.70E-02	3.13E-01	1.72E-01	1.30E-01
Fe	1.67E-01	00E 00	3.41E-01	1.69E-01	1.71E-01
Ba	4.59E-02	2.04E-02	5.12E-02	3.91E-02	1.65E-02
Mn	4.17E-02	1.79E-02	4.27E-02	3.41E-02	1.40E-02
Ni	1.17E-02	1.30E-02	1.88E-02	1.45E-02	3.77E-03
Sr	5.84E-03	8.14E-04	6.83E-03	4.49E-03	3.22E-03
Na	6.26E-01	4.55E-01	---	---	---
Cd	1.54E-02	---	5.69E-02	---	---
V	---	2.85E-03	1.08E-02	---	---
Mo	---	2.04E-03	3.98E-03	---	---
Al	---	3.34E00	---	---	---
Cu	---	6.84E-01	---	---	---
Pb	---	3.79E-02	---	---	---
Cr	---	5.29E-03	---	---	---

* Average
† Standard deviation

TABLE 32. IMPINGER CATCH METALS MASS RATE (g/hr)

Elements	Test Number 1	2	3	$\bar{X}$*	St
Si	1.96E01	7.66E01	3.07E01	4.23E01	3.02E01
S	2.11E01	4.98E01	3.37E01	3.49E01	1.44E01
Na	4.33E00	1.46E01	2.91E01	1.60E01	1.24E01
Al	2.43E00	1.07E01	3.07E00	2.19E00	1.02E00
Ba	3.61E-01	2.69E-01	2.27E-01	2.86E-01	6.85E-02
Zn	1.00E01	---	2.09E-02	---	---
Ni	1.66E-02	---	4.24E-02	---	---
Cd	4.79E-01	---	---	---	---
Ag	1.26E-01	---	---	---	---

* Average
† Standard deviation

The collection and treatment system contains the following components. Ash was cooled in a quench tank and was then pumped into a thickener. Thickened ash was drained into a screw type ash classifier consisting of a settling tank from which ash was dewatered by an inclined screw. The dewatered ash was dropped onto a flat belt conveyor system with three transfer points prior to deposition in containers for disposal.

Problems plaguing the system included plugging of pump suctions, refusal of the ash fines to thicken resulting in blockage of the system piping, inability to dewater the sludge causing flooding and spillage of materials from the conveyor system and blockages of the boiler ash transport systems due to the introduction of moisture.

To resolve these problems, a dry ash system has been installed which has been effective, clean, easy to operate, and so far trouble free. The heart of the system is a cleaner machine called a screw cooler. It consists of a screw-type conveyor that has a water jacket, a cooled end plate on the outside and a unique water cooled screw. The flights of the screw are of a continuous double walled construction in which cooling water flows up the flights of the screw and then back through the shaft of the screw. Experience has shown the machine to be extremely efficient at cooling the hot ash. There are four separate coolers, one located at the bottom of each of the hot dual cyclone separates. The discharge of each cooler contains a rotary air lock which seals the unit, and the entire cooler runs at whatever pressure the exhaust gas system is. The boiler ash hoppers are emptied through rotary air locks into a pneumatic transport system that utilize two small cyclone separators and a baghouse. The cyclones empty into the ash coolers and the baghouse empties directly onto the discharge conveyor. The discharge conveyor system is a series of three sealed screw conveyors which eliminated dust. (The original change utilized the best conveyors but they could not effectively be sealed. This created a small dust storm each time they were operated). The screw conveyors discharge directly into covered containers built specifically for that purpose. The scrubber ash system has been changed only in the scrubber discharges are pumped to the head of the wastewater plant.

Fly Ash Slagging

Fly ash slagging has occurred periodically in the system and has caused system shutdowns on several occasions. Investigations suggested that the slagging problem was aggrevated by unburned material leaving the bed area and that carbon carryout was involved in the smelting that created the slag. A number of different operational changes were tried with little success in an attempted to reduce freeboard burning or cool the exhaust to a point below which fusion or smelting initiation cculd not occur. To this end, a water spray nozzle was installed in the exhaust duct. It was found that maintaining the exhaust temperature at 1300°F no slag would be produced, but at 1350°F some slag would begin to form. However, at these temperatures, the FRC system could not produce sufficient steam to make the system self supporting.

Because the sludge contains some paper mill wastes, it has a low fusion point. Therefore it may be necessary to provide some form of exhaust gas cooling to prevent slagging. However, because with a cooling spray, the excessive amount of latent heat is lost to the cooling spray, the excessive amount of latent heat is lost to the cooling water thereby reducing the waste heat boiler output. Alternative methods of achieving exhaust gas cooling are being investigated. Furthermore, means to confine combustion to the bed area are being explored. This would permit the burning of more material with a higher fluidizing air flow and at low enough temperatures to prevent slagging but with enough mass flow to produce slagging but with enough mass flow to produce sufficient steam to run the process.

SECTION 5

DISCUSSION OF MATHEMATICAL MODEL OF THE COMBUSTOR SYSTEM

INTRODUCTION

The operation of the fluidized-bed combustor is monitored by extensive process control instumentation. Historical data collected from this instrumentation can be combined with theoretical combustion equations to form a basis for predicting the effects of changes in fuel properties and air and fuel input rates. A mathematical model of the fludidized bed combustor could give the system operator the tool needed to optimize bed tempterature, steam production and auxiliary fuel usage.

A mathematical model of the system was developed which could provide a materials and energy balance of the system. This model uses the basic stoichiometric and the modynamic equations of combustion and calculates an adiabatic flame temperature for the combustion reaction. Combustor exhaust temperature is usaully close to adiabatic flame temperature. Historical operating data was used to develop an equation to predict actual fuel bed temperature.

Since most of the mechanical drives of the system are powered by steam produced after the combustion process, the model also calculates the steam produced and the steam needed to operate the system. There are volume and mass flow limitations in the scrubber and flue gas handling system which the operator must be careful not to exceed. Therefore, the mathematical model also calculated these flows for comparison to the limits.

Because this mathematical model is large and iterative, it would be very tedious to manually calculate even one set of solutions for the model. Therefore, the model was encoded into computer language to make its use practical.

The computerized mathematical model was verified by inputing historical fuel and air data and observing that the computer program accurately calculated the system temperatures and flow rates.

The computer model, "HEATBAL," has six modes of analyses which permits the user to:

1. Compute the amount of auxiliary fuel, fluidizing air and overbed air necessary to produce the maximum possible boiler steam output while maintaining given operating conditions in the combustor.

2. Compute the maximum amount of auxiliary fuel and fluidizing air needed to maintain acceptable operating temperatures and produce sufficient steam to operate the steam turbines.

3. Compute the amount of auxiliary fuel and fluidizing air necessary to produce a desired steam rate or the steam rate necessary to operate the turbines, whichever is larger.

4. Estimate how the combustor would operate with specified inputs. The feasibility of operating in that mode must be decided by the user.

5. Compute the impact of using an economizer to effect preheating of the boiler feed water by using heat in boiler exhaust gas on computed values in Modes 1, 2, 3, or 4.

6. Compute the impact of a combustion air preheater on values computed in Modes 1, 2, 3, or 4.

"HEATBAL" was designed to simulate the operation of the fluidized-bed combustors at WLSSD. The source code of the model is written in HP-3000 Fortran. The source code is divided into modules and subroutines with numerous comment lines and long, descriptive variable names. Efficiency and elegance have been sacrificed to make the source code easy to understand and easy to modify by another programmer.

The object code resulting from the compilation of this source code can be stored for interactive execution from a video terminal. Successive runs of the program are possible in the same session without terminating the program and restarting.

OPERATING THE PROGRAM

Upon initiating a run of this program, the user will first be asked if they want a list of the available modes of analysis. The following list will then be displayed if the user responds "Y":

1. Maximum Steam Production
2. Minimum Auxiliary Fuel Usage
3. Specified Steam Production
4. Exhaust Temperature (Heatwork)
5. An Economizer With Any Mode
6. An Air Preheater With Any Mode

The user must then specify the mode of analysis desired for this run.

Available Modes

Mode 1. Maximum Steam Production--In this mode the user must specify a sludge feed rate and whether he/she wishes to use wood or RDF as the auxiliary fuel. The program will then compute the amount of auxiliary fuel (without using fuel oil), fluidizing air (FAB), and overbed air necessary to produce the maximum possible boiler steam output while keeping combustor temperatures and flow rates within the desired ranges. This program assumes that 104×10^6 Btu/hr is the maximum permissible heat input to the combustor. Mode 1 is the only mode in which overbed air is automatically added once the upper limit for fluidizing air is reached. The combined volume of overbed air and fluidizing air is never permitted to exceed 29,000 CFM. Although the mid-bed temperature is calculated, there is no logic supplied to adjust that temperature to an acceptable value. The reported value for bed temperature in this mode is probably inaccurate since at the time this program was written there were no data available to model the behavior of bed temperature at high firing rates with overbed air.

Mode 2. Minimum Auxiliary Fuel--In this mode the user will specify a sludge feed rate and an auxiliary fuel type. The program will compute the minimum amount of auxiliary fuel and FAB that is necessary to maintain acceptable operating temperatures while producing just enough steam to operate the system turbines. This mode does not provide for the use of fuel oil. There is no function to determine the proper amount of overbed air; however, overbed air can be included at a specified rate through the STORED VALUES as explained below.

Mode 3. Specified Steam Production--This mode uses the same calculation logic as Mode 2, but differs in that the program will ask for a desired steam production rate. In this mode the program will calculate the amounts of auxiliary fuel and FAB necessary to produce the requested steam rate or the steam rate necessary to operate the turbines, whichever is larger. Since this mode attempts to satisfy so many conditions simultaneously, execution often takes considerable CPU time.

Mode 4. Heatwork--This mode contains the least decision logic of any mode. The user must specify all fuel and air inputs. The program will only check to assure the user does not specify a substoichiometric air input. Similar to the "Heatwork" programs previously used at WLSSD, this analysis mode does not determine how the combustor should be operated. It estimates how the combustor would operate with the specified inputs. This mode has many advantages. Four different fuels and three air inputs can be specified to occur simultaneously. There is always a solution to a Mode 4 computation, but it is up to the user to decide whether or not the solution is feasible.

Mode 5. Economizer--Mode 5 must be used in conjunction with Modes 1, 2, 3, or 4. When Mode 5 is specified, the user will be asked what boiler outlet (economizer outlet) temperature is desired. The program will then start over by asking to which mode of analysis the system including economizer will be subjected. The user may then answer with any other mode except Mode 5.

An economizer is assumed to be an additional heat exchanger that preheats the boiler feedwater by using heat in the boiler exhaust gas. In effect, an economizer improves boiler efficiency by reducing the boiler exhaust temperature. The program will not accept a boiler exhaust temperature of less than 350°F. If a lower temperature is entered, the program will ignore it and assign 350°F. If a temperature above 530°F is entered, the economizer will become an "uneconomizer" because 530°F is the normal boiler exhaust temperature.

Mode 6. Air Preheater--Like Mode 5, Mode 6 must be used in conjunction with one of the other modes. When Mode 6 is specified the program will ask what FAB temperature is desired. Once this temperature is entered the program will again ask "which mode of analysis do you wish to use?" The response must be a 1, 2, 3, or 4. The program will then plug a combustion air preheater into the system being analyzed in the chosen mode. Note that both an economizer and an air preheater can be specified simultaneously by requesting Mode 5, then Mode 6, then Mode 1, or 2, or 3, or 4. That particular sequence is important. Do not specify Mode 6 then Mode 5 in the same analysis.

The air preheater extracts heat from the boiler exhaust gas to heat the FAB and overbed air. Heat can only be extracted from the flue gas until FAB temperature equals the flue gas temperature. This limitation is built into the program. Therefore, no matter what FAB temperature is specified the program will not permit it to be higher than the resulting flue gas temperature.

In any subsequent analysis run during the same session, the air preheater and/or economizer will be deleted unless Mode 5 or 6 is again specified.

Stored Values

After a mode is entered the program will ask the operator "do you wish to change any of the STORED VALUES?" The STORED VALUES contain 56 constants that are used throughout the program. Upon starting a session with the program these stored constants are assigned values by a BLOCK DATA subroutine. These constants and their initial values are shown in Table 33. These "STORED VALUES" can be changed during each run, and the new value assigned will be retained in every subsequent analysis until the value is changed again or the session ended. The operator can get the current value of each stored constant by answering "Y" to "do you want a display of the STORED VALUES?" Since all 56 values cannot be displayed at once on a screen, only the first 32 are displayed initially. At that time the only option is to enter the word "RESUME" to display the last 24 values and continue the program. Note that each stored value has a "location." To change a stored value enter its location number. The program will return and ask for the value to be assigned to that location. To stop the program from requesting new locations and values enter "-1" for location.

TABLE 33. STORED VALUES

Location	Constant	Value
1	Sludge carbon	42.0 percent
2	Sludge hydrogen	6.0 percent
3	Sludge oxygen	20.0 percent
4	Sludge nitrogen	2.5 percent
5	Sludge sulfur	0.5 percent
6	Sludge ash	29.0 percent
7	Wood carbon	53.0 percent
8	Wood hydrogen	6.0 percent
9	Wood oxygen	38.0 percent
10	Wood nitrogen	0.0 percent
11	Wood sulfur	0.0 percent
12	Wood ash	3.0 percent
13	RDF carbon	45.0 percent
14	RDF hydrogen	5.0 percent
15	RDF oxygen	25.0 percent
16	RDF nitrogen	0.7 percent
17	RDF sulfur	0.3 percent
18	RDF ash	24.0 percent
19	Fuel oil carbon	87.2 percent
20	Fuel oil hydrogen	12.2 percent
21	Fuel oil oxygen	0.0 percent
22	Fuel oil nitrogen	0.0 percent
23	Fuel oil sulfur	0.3 percent
24	Fuel oil ash	0.0 percent
25	Sludge solids	17.0 percent
26	Wood solids	55.0 percent
27	RDF solids	75.0 percent
28	Fuel oil dryness	100.0 percent
29	Sludge HHV	7600 Btu/lb
30	Wood HHV	8700 Btu/lb

(continued)

TABLE 33. (continued)

Location	Constant	Value
31	RDF HHV	6700 Btu/lb
32	Fuel oil HHV	19,500 Btu/lb
33	Atomizing steam	1000 lb/hr
34	FAB temperature	140°F
35	FAB pressure	60 in. H_2O
36	Maximum FAB air	19,000 ACFM
37	Minimum FAB air	10,500 ACFM
38	Overbed air (OBA)	0 ACFM
39	OBA temperature	140°F
40	OBA pressure	60 in. H_2O
41	Pneumatic feeder air	3800 SCFM
42	Pneumatic air temperature	100°F
43	Maximum combustor exhaust temperature	1750°F
44	Maximum combustor exhaust temperature	1450°F
45	Maximum bed temperature	1450°F
46	Minimum bed temperature	1350°F
47	Excess air	20 percent
48	Ambient humidity	.01 lb/lb
49	Ambient temperature	70°F
50	F.W. and scrubber pump power	175 HP
51	Scrubber inlet tempterature	490°F
52	Scrubber outlet temperature	120°F
53	Fuel oil density	7.28 lb/gal
54	Maximum ID power	610 Hp
55	Maximum ID volume	50,000 ACFM
56	Thickened sludge solids	6 percent

The following is an explanation of the individual STORED VALUES.

Locations 1 through 24	Ultimate analysis values are on a dry weight basis. When changing any of these values, be sure that the ultimate analysis of each fuel adds up to 100 percent. Note that the ultimate analysis of coal, hazardous waste, or any other material can be substituted for any of these ultimate analyses.
Locations 25 through 28	Solids content of each fuel is on a wet basis at the point the fuel is fed into the combustor.
Locations 29 through 32	Higher heating value of each fuel is on a dry weight basis.
Location 33	The amount of steam used to atomize sludge in the top of the combustor.
Locations 34 and 35	Conditions of the FAB. Do not change these in Mode 6.
Locations 36 and 37	The maximum and minimum acceptable FAB rates.
Location 38	Overbed air in Modes 2, 3, and 4. This is the only mechanism for introducing overbed air in those modes. In Mode 1 the program will start with this amount of overbed air and adjust it only if necessary to keep FAB in range.
Locations 39 and 40	Conditions of the overbed air. In Mode 6 these will be assigned the same values as FAB conditions.
Locations 41 and 42	The volume and temperature of air used for the pneumatic feeding of wood or RDF.
Locations 43 and 44	These are the maximum and minimum acceptable combustor exhaust temperatures.
Locations 45 and 46	These are the maximum and minimum acceptable mid-bed temperatures.
Location 47	In Modes 1, 2, and 3 this is the excess-air level the program will try first. In Mode 4 this stored value is not used.

Locations 48 and 49	These are the ambient temperature and ambient humidity ratio storage locations. Humidity ratio is in pounds of water vapor per pound of dry air. At 70°F, .01 lb/lb represents 63 percent relative humidity.
Location 50	This location stores the normal combined turbine power demand of the feedwater and scrubber pumps.
Location 51	This location stores the normal scrubber inlet flue gas temperature. Do not attempt to alter this value when using Modes 5 or 6.
Location 52	This scrubber exhaust temperature is what the program will attempt to provide. If more than 1000 GPM of scrubber water is necessary to achieve this exhaust temperature, the program will alter the temperature upward until it is within the capacity of the scrubber pump.
Location 53	The density of fuel oil is stored in this location. This value can be altered if a liquid hazardous waste or some other fuel is substituted for fuel oil in a Mode 4 analysis.
Locations 54 and 55	This location stores the power and volume limits of the induced-draft fan.
Location 56	This location is for the solids content of the thickened sludge as it is fed to the belt presses. This program assumes that the only location for sludge flow measurement is at the inlet to the belt press.

If the program user wishes to feed thickened sludge rather than dewatered sludge to the combustor, be sure to set the value in Location 25 equal to the value in Location 56.

Any of the STORED VALUES can be permanently changed by altering the block data portion of the source code and recompiling the program.

Energy Balance Display

The results of each analysis will be output in a single display on the screen titled "Energy Balance." Each item of the display is explained in the following paragraphs.

The thickened sludge rate is displayed exactly as input by the user. The solids content is Stored Value 56. This program assumes that sludge flow rate is measured in the thickened state.

Sludge rate to combustor is computed by converting the thickened sludge to the solids content of Stored Value 25. If thickened sludge is fed to the combustor, the solids content to the combustor should be the same as thickened sludge solids.

Wood rate and RDF rate will be the optimum as calculated by Modes 1, 2, and 3, or they will be as input by the user for Mode 4. Fuel oil rate can be assigned a non-zero value only by the user and only in Mode 4.

Total heat release is the summation of heating values multiplied by the mass rates of fuels into the combustor. In Modes 1, 2, and 3 it is assumed that the combustor has a maximum input capacity of 104×10^6 Btu/hr.

Overbed air rate must be entered by the user in Modes 2, 3, and 4. In Mode 1 appropriate overbed air rate is calculated. Furthermore, in Mode 1 the program will not allow the total of overbed air plus FAB to exceed the Roots blower capacity of 29,000 CFM. In Modes 2, 3, and 4 the user must be careful to keep this total in range. The overbed air temperature will be as stored in Location 39 unless the analysis begins with a Mode 6. In the latter case overbed air temperature will be the same as the FAB temperature specified by the user.

The FAB displayed will be as calculated by the program in Modes 1, 2, and 3. The program will attempt to keep FAB within the limits specified in Storage Locations 36 and 37. In Mode 4 the FAB is input by the user. The FAB temperature will be as STORED VALUE 34 unless the user inputs a different value in a Mode 6 analysis.

The combustor exhaust temperature is the adiabatic flame temperature of the fuel/air mixture into the combustor. As is typical with adiabatic flame temperatures, this number may error on the high side, but it represents the best estimate that can be made. In Modes 1, 2, and 3 the program will adjust the fuel and air inputs to keep the exhaust temperature within the range specified by Stored Values 43 and 44.

The mid-bed temperature is calculated by an equation developed through a multiple linear regression analysis of a rather limited data set. The data from which the model was derived included eight observations of conditions in the following ranges:

- Heat input — 63×10^6 to 86×10^6 Btu/hr
- Excess air — 13 to 50 percent
- Exhaust temperatures — 1390 to 1671°F
- Flue gas moisture — 30 to 40 percent

If the analyzed conditions are outside these ranges, the reported mid-bed temperature could be in error. Another limitation the user should be aware of is the lack of information on the effect of overbed air at the time this model was developed. The mid-bed temperature cannot be relied upon if any overbed air is used in the analysis. Finally, if the mid-bed temperature exceeds the combustor exhaust temperature, the mid-bed temperature is probably erroneous.

The steam output of the boiler is calculated by a heat balance around the boiler which uses a calculation procedure similar to ASME PTC 4.1. This calculation assumes a 10 percent radiative/convective surface loss and no losses due to combustibles remaining in the residue or fly ash.

The turbine steam demand is calculated from typical performance curves of the turbines which drive the FAB and ID fans and the feedwater and scrubber pumps. Please note that this steam demand figure does not include the steam used to atomize sludge.

Boiler exit gas temperature will always be 530°F unless that temperature is altered by an economizer, as in a Mode 5 analysis. The scrubber water input will be some quantity less than 1000 GPM, the assumed pump capacity. The gas temperature into the scrubber will be 40°F below the temperature of the boiler, economizer, or air preheater exhaust. This temperature difference is normally needed to operate the stack gas heat exchanger. Scrubber water output includes scrubber water input plus condensed flue gas moisture.

The gas temperature at the exit of the scrubber is assumed identical to the temperature of the scrubber water output. This temperature will be the same as Storage Position 52 unless some higher temperature is computed to keep the scrubber waterflow less than 1000 GPM.

The ID fan flow rate is computed for actual conditions at the fan. If the flue gas quantities exceed the fan capacity, the fan capacity is displayed here and an error message will appear below. The ID fan power is estimated from the fan curve. If the required power exceeds the capacity of the turbine, the turbine capacity is displayed and an error message is displayed below.

The excess air level at the combustor outlet is displayed. Often this excess air level will be the same as stored Value 47. If necessary the program will adjust the excess air level to maintain acceptable operating conditions. The oxygen concentration corresponding to the combustor outlet excess air is also displayed.

OTHER PROGRAM OPERATING NOTES

If the user answers "Y" to the question "Do you wish to make another run?" all the STORED VALUES will be restored to what they were after the last time they were accepted or changed. If the user answers "N", the program will

end and all STORED VALUES will go back to their original default values. The current stored values can be observed by answering "Y" to the question "Do you wish to have a display of the STORED VALUES?"

The combustion of any fuel or waste in the fluidized bed can be analyzed by substituting other fuel properties in Stored Values 1 to 32. The user must only make sure that each ultimate analysis is on a dry weight basis and adds up to 100 percent.

Values labed "PCT" must be entered as percentage numbers. The programs will automatically divide these numbers by 100 before using them. When the program asks for a LOCATION or a MODE, the user must be careful to enter only integers (no decimal point) that are in the proper range.

When interpreting the results of analysis the user must note that all results are steady state solutions. For example, an operating condition that provides a higher steam output along with a higher mid-bed temperature, may actually produce a reduced steam output initially until the bed temperature equilibrates. It is estimated that over 1 million Btu's are required to increase the bed temperture 15° to 20°F.

A listing of the source code of the program is given in Appendix C.

APPENDIX A

BASIC DESIGN DATA

Wastewater Flows and Loads		Loading for Solid Waste Processing
1990 connected population	136,335	Two trains @280 ton/day each.
Average flow, MGD	43.63	Based on 14 hr/day,
Peak flow, MGD	86.57	5 day/wk operation.
BODs lbs/24 hr	97,658	
SS lbs/24 hr	61,896	
P lbs/24 hr	1,100	

Wastewater Treatment	
Influent wastewater pumps	5 units at 12 MGD each
72" dia. variable capacity screw pumps	
Influent screens, mechanical bar screens	3 units
Grit tanks, detritor	2 units at 43 MGD each
Surface settling rate	17,314 gal/s.f./day at OP
Oxygenation tanks, 4 stage	4 trains
Detention time	2.68 hours at Qa
RAS flow rate	60% Qa
Oxygen purity	90%
Mixed liquor suspended solids	4,000 mg/l
Bio-mass loading	0.66 lbs BOD5/lb MLSS
Pounds oxygen per lbs. BOD5 removed	1.25
Cyrogenic oxygen generators	3 units at 45 ton/day
Secondary settling tanks (dome covered)	4 tanks at 160' dia.
RAS flow rate	26.2 MGD
Overflow rate	543 gal/s.f./day
Detention time	462 hours at Qa
Flocculation and settling tanks (dome covered)	4 tanks at 120' dia.
Overflow rate	965 gal/s.f./day
Detention time	2.7 hours at Qa
Equipped for mixing of alum and polyelectrolyte for phosphorus removal	All tanks
Final effluent filters (mixed media)	12 units
Total filter area	7,776 s.f.
Filter surface loading	3.9 gpm/s.f.
Chlorine contact tanks	2 tank
Volume	125,000 cu. ft
Detention time	15 min. at Qp
Chlorinators and evaporators	4 units ea. at 8,000 lb/day
Tank car unloading	2 units
Dechlorination tanks	1 tank
Sulfurators	2 units at 2,000 lb/day

Wastewater Treatment (continued)

Sludge thickening facility	4 units
Type	Flocculation
RAS	87,000 lb/day
Chemical sludge	20,000 lb/day
Surface loading rate	1.85 lb/s.f./hr
Vacuum filtration	4 units
Total sludge	96,200 lb/day
Moisture content	80%
Design yield	291 lb/s.f./hr

Solid Waste Processing and Sludge Disposal

Processing

Truck scale	50 ton capacity
Refuse loading	400 ton/day
Pit conveyors	2 @ 30 ton/hr
Feed conveyor	4 @ 30 ton/hr
Coarse shredder	2 @ 30 ton/hr
Magnetic separators	2 units
Fine shredder air classifiers	2 @ 30 ton/hr
Transfer conveyors	1 @ 60 ton/hr
	1 @ 30 ton/hr
Fuel transport conveyors	3 @ 60 ton/hr
	2 @ 20 ton/hr
Ferrous metal conveyors	3 @ 6 ton/hr
Noncombustible conveyors	2 @ 18 ton/hr
Storage bin outfeed conveyor	1 @ 20 ton/hr
Fuel storage bin	2 day storage @ 350 ton/day

Disposal

Fluidized-bed reactors	2 units
Sludge input	5,690 lb/hr dry solids
Prepared refuse input (160 ton/day)	13.33×10^3 lb/hr
Wood chips	12.6×10^3 lb/hr
Heat input	
Sludge	30.78×10^6 BTU/hr
Refuse	73.32×10^6 BTU/hr
Reactor operating temperature	1,600°F
Exhause gas temperature	1,400°F
Waste heat recovery boiler	2 units
Steam generating capacity	48,000 lb/hr
Steam temperature and pressure	280 psig (saturated)
Boiler design pressure	400 psig
Flue gas temperature	570°F
Auxiliary fuel	2 tanks @ 30,000 gal each
fuel oil tanks	

Solid Waste Processing and Sludge Disposal (continued)

Air pollution control

Wet scrubbers	2 units
Maximum particulate emission	0.03 gr/dscf
Maximum smoke opacity	10%
Flue gas temperature leaving scrubber	130°F
Flue gas temperature leaving heat exchanger	250°F
Stack height above roof	44 ft
Stack height aboveground	131 ft
Stack inside diameter	60 in.

APPENDIX B

NBS-FLY-ASH
NBS 1633

Element	Standard µg/g	Found
Ag	.25	<2
Al	12.5%	12.7%
As	61	65
Ba	2700	2700
Be	12	14
Ca	4.6%	4.5%
Cd	1.5	1.9
Co	40	43
Cr	129	131
Cu	127	127
Fe	6.2%	6.3%
K	1.7%	1.6%
Li	110	111
Mg	1.6%	1.5%
Mn	492	502
Mo	29	28
Na	3200	3100
Ni	98	102
P	890	880
Pb	72	75
S	4000	3900
Sb	6.9	<6
Se	9.6	<8
Sn	9.4	<12
Sr	1400	1300
Ti	7200	7400
Tl	4.1	<9
V	216	220
Y	65	68
Zn	213	220

MUNICIPAL SLUDGE

Element	Theoretical µg/g	Found
Al	4600	4700
Be	0.28	0.31
Cr	204	207
Cu	1095	1100
Fe	16100	17000
Mn	205	210
Ni	198	201
Pb	519	525
V	13	14
Zn	1320	1300
Cd	21	23
Ag	81	83
Ti	2100	2200
As	17	<20
Hg	16	20

APPENDIX C
HEATBAL COMPUTER MODEL

```
PAGE 1     HEWLETT-PACKARD 32201A.7.12 EDIT/3000 MON, JUL  9, 1984, 11:11 AM (C) HEWLETT-PACKARD CO. 1982


    1     $CONTROL USLINIT
    2     $CONTROL NOLIST
    3           PROGRAM HEATBAL
    4           REAL N2MASS,N2VF,NITROGEN,N,MOYNOGPM
    5           DIMENSION C(33),D(13),E(6),F(4)
    6           COMMON/INTEG/INVOKE1,INVOKE2,INVOKE3,INVOKE4,INVOKE5,INVOKE6
    7           COMMON/FUELS/ULTI(6,4),TS(4),HHV(4),STEAMIN
    8           COMMON/VALUES/FABTEMP,FABPRESS,FABMAX,FABMIN,OBASCFM,OBATEMP,OBA
    9          +PRESS,PNAIR,PNTEMP,EXHTEMPMAX,EXHTEMPMIN,BEDTEMPMAX,BEDTEMPMIN
   10           COMMON/AERO/EA,HUMIDITY,TEMPAMB,PUMPHP,TEMPIN,TEMPOUT
   11           COMMON/MAINS/OILDENSITY,HPMAXID,CFMMAXID,TSTHICK
   12           COMMON/ELEMENTS/CARBON,HYDROGEN,OXYGEN,NITROGEN,SULFUR,ASH,WATER
   13           COMMON/GASSES/CO2MASS,H2OMASS,O2MASS,N2MASS,SO2MASS,FLUGASCFM,
   14          +CO2VF,H2OVF,O2VF,N2VF,SO2VF,DSCFM
   15           EQUIVALENCE (ULTI(1,1),C(1)),(FABTEMP,D(1)),(EA,E(1))
   16           EQUIVALENCE (OILDENSITY,F(1))
   17           DATA Y/1HY/,N/1HN/,R/1HR/,W/1HW/,LASTMODE/0/,OILGPM/0./
  100     C
  101     C****************** INPUT OF DATA SECTION ******************
  102     C
  103     C
  104     C
  105           WRITE (6,100)
  106       100 FORMAT(/T5,"DO YOU WISH FOR A DISPLAY OF THE POSSIBLE MODES OF
  107          +",/T3," ANALYSIS ?(Y/N) ")
  108           READ (5,920) Q
  109           IF (Q,NE,Y) GO TO 230
  110           WRITE (6,102)
  111       102 FORMAT(/T35,"MODES OF ANALYSIS",//T5,"1. MAXIMUM STEAM PRODUCTION
  112          + ",/T5,"2. MINIMUM AUXIALLIARY FUEL USAGE",/T5,"3. SPECIFIED STEAM
  113          + PRODUCTION",/T5,"4. EXHAUST TEMP. (HEATWORK)",
  114          + /T5,"5. ANY MODE WITH AN ECONOMIZER ",
  115          + /T5,"6. ANY MODE WITH AN AIR PREHEATER")
  116       230 BOEXTEMP = 530.
  117           WRITE (6,240)
  118       240 FORMAT (/T5,"PLEASE INPUT MODE OF ANALYSIS ")
  119           ACCEPT MODE
  120           GO TO 250
  121       245 EA = STORE1
  122           INVOKE1 = 0
  123           INVOKE2 = 0
```

```
124           INVOKE3 = 0
125           INVOKE4 = 0
126           INVOKE5 = 0
127           INVOKE6 = 0
128           TEMPOUT = STORE2
129           OBASCFM = STORE3
130            BOEXTEMP = 530.
131           OILGPM = 0.0
132           IF (LASTMODE.EQ.6) FABTEMP = STORE4
133           IF (LASTMODE.EQ.6) OBATEMP =STORE5
134           LASTMODE = 0
135        248 WRITE (6,240)
136           ACCEPT MODE
137        250 IF (MODE.GT.4) GO TO 451
138           WRITE (6,251)
139        251 FORMAT(/T5,"DO YOU WISH TO CHANGE ANY OF THE STORED VALUES ?
140          +(Y/N)")
141           READ (5,920) Q
142           IF (Q.NE.Y) GO TO 370
143           WRITE (6,252)
144        252 FORMAT (/T5,"DO YOU WISH TO HAVE A DISPLAY OF THE STORED VALUES
145          + ? (Y/N)")
146           READ (5,920) Q
147           IF  (Q.NE.Y) GO TO 359
148        C START THE LISTINGS OF STD VALUES HERE
149           WRITE (6,254)
150        254 FORMAT (/T35,"STORED VALUES",//," LOCATION",T11,"CONSTANT",
151          + T27,"VALUE",T38,"LOCATION",T49,"CONSTANT",T65,"VALUE")
152           WRITE (6,255) ULTI(1,1),ULTI(2,1)
153        255 FORMAT ( ,"  1.",T5,"SLUDGE CARBON",T24,F4.1,T30,"PCT",
154          + T38,"  2.",T44,"SLUDGE HYDROGEN",T64,F4.1,T70,"PCT")
155           WRITE (6,256) ULTI(3,1),ULTI(4,1)
156        256 FORMAT ( ,"  3.",T5,"SLUDGE OXYGEN",T24,F4.1,T30,"PCT",
157          + T38,"  4.",T44,"SLUDGE NITROGEN",T64,F4.1,T70,"PCT")
158           WRITE (6,257) ULTI(5,1),ULTI(6,1)
159        257 FORMAT ( ,"  5.",T5,"SLUDGE SULFUR",T24,F4.1,T30,"PCT",
160          + T38,"  6.",T44,"SLUDGE ASH ",T64,F4.1,T70,"PCT")
161           WRITE (6,258) ULTI(1,2),ULTI(2,2)
162        258 FORMAT ( ,"  7.",T5,"WOOD CARBON",T24,F4.1,T30,"PCT",
163          + T38,"  8.",T44,"WOOD HYDROGEN",T64,F4.1,T70,"PCT")
164           WRITE (6,259) ULTI(3,2),ULTI(4,2)
165        259 FORMAT ( ,"  9.",T5,"WOOD OXYGEN",T24,F4.1,T30,"PCT",
166          + T38," 10.",T44,"WOOD NITROGEN",T64,F4.1,T70,"PCT")
167           WRITE (6,260) ULTI(5,2),ULTI(6,2)
168        260 FORMAT ( ," 11.",T5,"WOOD SULFUR",T24,F4.1,T30,"PCT",
169          + T38," 12.",T44,"WOOD ASH",T64,F4.1,T70,"PCT")
170           WRITE (6,261) ULTI(1,3),ULTI(2,3)
171        261 FORMAT ( ," 13.",T5,"RDF CARBON ",T24,F4.1,T30,"PCT",
172          + T38," 14.",T44,"RDF HYDROGEN",T64,F4.1,T70,"PCT")
173           WRITE (6,262) ULTI(3,3),ULTI(4,3)
174        262 FORMAT ( ," 15.",T5,"RDF OXYGEN ",T24,F4.1,T30,"PCT",
175          + T38," 16.",T44,"RDF NITROGEN",T64,F4.1,T70,"PCT")
176           WRITE (6,263) ULTI(5,3),ULTI(6,3)
```

```
177       263 FORMAT ( ," 17.",T5,"RDF SULFUR ",T24,F4.1,T30,"PCT",
178          + T38,"| 18.",T44,"RDF ASH",T64,F4.1,T70,"PCT")
179           WRITE (6,264) ULTI(1,4),ULTI(2,4)
180       264 FORMAT ( ," 19.",T5,"FUEL OIL CARBON ",T24,F4.1,T30,"PCT",
181          + T38,"| 20.",T44,"FUEL OIL HYDROGEN",T64,F4.1,T70,"PCT")
182           WRITE (6,265) ULTI(3,4),ULTI(4,4)
183       265 FORMAT ( ," 21.",T5,"FUEL OIL OXYGEN ",T24,F4.1,T30,"PCT",
184          + T38,"| 22.",T44,"FUEL OIL NITROGEN",T64,F4.1,T70,"PCT")
185           WRITE (6,266) ULTI(5,4),ULTI(6,4)
186       266 FORMAT ( ," 23.",T5,"FUEL OIL SULFUR ",T24,F4.1,T30,"PCT",
187          + T38,"| 24.",T44,"FUEL OIL ASH",T64,F4.1,T70,"PCT")
188           WRITE (6,267) TS(1),TS(2)
189       267 FORMAT ( ," 25.",T5,"SLUDGE SOLIDS ",T24,F4.1,T30,"PCT",
190          + T38,"| 26.",T44,"WOOD SOLIDS ",T64,F4.1,T70,"PCT")
191           WRITE (6,268) TS(3),TS(4)
192       268 FORMAT ( ," 27.",T5,"RDF SOLIDS",T24,F4.1,T30,"PCT",
193          + T38,"| 28.",T44,"FUEL OIL DRY",T64,F5.1,T70,"PCT")
194           WRITE (6,269) HHV(1),HHV(2)
195       269 FORMAT ( ," 29.",T5,"SLUDGE HHV",T24,F5.0,T30,"BTU/LB",
196          + T38,"| 30.",T44,"WOOD HHV ",T64,F5.0,T70,"BTU/LB")
197           WRITE (6,270) HHV(3),HHV(4)
198       270 FORMAT ( ," 31.",T5,"RDF HHV",T24,F5.0,T30,"BTU/LB",
199          + T38,"| 32.",T44,"FUEL OIL HHV ",T64,F6.0,T70,"BTU/LB",//)
200           PAUSE "; TO CONTINUE ENTER 'RESUME'"
201           WRITE (6,271) STEAMIN,FABTEMP
202       271 FORMAT ( ," 33.",T5,"ATOMIZING STEAM",T24,F5.0,T30,"LB/HR",
203          + T38,"| 34.",T44,"FAB TEMP.",T64,F4.0,T70,"F")
204           WRITE (6,272) FABPRESS,FABMAX
205       272 FORMAT ( ," 35.",T5,"FAB PRESS.",T24,F4.1,T30,"IN H2O",
206          + T38,"| 36.",T44,"MAX FAB AIR",T64,F6.0,T70,"ACFM")
207           WRITE (6,273) FABMIN,OBASCFM
208       273 FORMAT ( ," 37.",T5,"MIN FAB AIR",T24,F6.0,T30,"ACFM",
209          + T38,"| 38.",T44,"OVER BED AIR",T64,F5.0,T70,"ACFM")
210           WRITE (6,274) OBATEMP,OBAPRESS
211       274 FORMAT ( ," 39.",T5,"OBA TEMP.",T24,F4.0,T30,"F  ",
212          + T38,"| 40.",T44,"OBA PRESS.  ",T64,F4.1,T70,"IN H2O")
213           WRITE (6,275) PNAIR,PNTEMP
214       275 FORMAT ( ," 41.",T5,"MAC FEEDER AIR",T24,F5.0,T30,"SCFM",
215          + T38,"| 42.",T44,"PNEUMATIC AIR TEMP",T64,F4.0,T70,"F")
216           WRITE (6,276) EXHTEMPMAX, EXHTEMPMIN
217       276 FORMAT ( ," 43.",T5,"MAX COMB EXH TEMP",T24,F6.0,T30,"F ",
218          + T38,"| 44.",T44,"MIN COMB EXH TEMP",T64,F5.0,T70,"F")
219           WRITE (6,277) BEDTEMPMAX, BEDTEMPMIN
220       277 FORMAT ( ," 45.",T5,"MAX BED TEMP",T24,F5.0,T30,"F ",
221          + T38,"| 46.",T44,"MIN BED TEMP",T64,F5.0,T70,"F")
222           WRITE (6,278) EA, HUMIDITY
223       278 FORMAT ( ," 47.",T5,"EXCESS AIR",T24,F4.1,T30,"PCT",
224          + T38,"| 48.",T44,"AMBIENT HUMIDITY",T64,F5.3,T70,"LB/LB")
225           WRITE (6,279) TEMPAMB, PUMPHP
226       279 FORMAT ( ," 49.",T5,"AMBIENT TEMP.",T24,F3.0,T30,"F",
227          + T38,"| 50.",T44,"F.D.+SCRUB. PUMP",T64,F6.1,T70,"HP")
228           WRITE (6,280) TEMPIN, TEMPOUT
```

```
229      280 FORMAT ( ,"  51.",T5,"SCRUB INLET TEMP",T24,F4.0,T30,"F",
230         + T38,"  52.",T44,"SCRUB OUTLET TEMP",T64,F4.0,T70,"F ")
231          WRITE (6,281) OILDENSITY,HPMAXID
232      281 FORMAT ( ,"  53.",T5,"FUEL OIL DENSITY",T24,F3.1,T30,"LB/GAL",
233         + T38,"  54.",T44,"MAX ID POWER ",T64,F4.0,T70,"HP")
234          WRITE (6,282) CFMMAXID,TSTHICK
235      282 FORMAT ( ,"  55.",T5,"MAX ID VOLUME",T24,F6.0,T30,"ACFM",
236         + T38,"  56.",T44,"THICKENED SLUDGE SOLIDS ",T64,F4.0,T70,"PCT")
237      359    WRITE (6,360)
238      360 FORMAT (/T5,"INPUT THE LOCATION NUMBER AND THE NEW VALUE.",
239         + /T5,"AFTER THE LAST CHANGE INPUT A LOCATION OF -1")
240      361 WRITE (6,363)
241      363 FORMAT (/T5,"INPUT LOCATION")
242          ACCEPT SOMETHING
243          LOCATION = SOMETHING
244          IF (LOCATION.LT.0) GO TO 370
245          WRITE (6,364)
246      364 FORMAT ( T5,"INPUT THE NEW VALUE")
247          ACCEPT VALUE
248          IF (LOCATION.GE.34.AND.LOCATION.LT.47) GO TO 366
249          IF (LOCATION.GE.47.AND.LOCATION.LT.53) GO TO 367
250          IF (LOCATION.GE.53) GO TO 368
251          C(LOCATION) = VALUE
252          GO TO 361
253      366 L = LOCATION - 33
254          D(L) = VALUE
255          GO TO 361
256      367 L = LOCATION - 46
257          E(L) = VALUE
258          GO TO 361
259      368 L = LOCATION - 52
260          F(L) = VALUE
261          GO TO 361
262      370 STORE1 = EA
263          STORE2 = TEMPOUT
264          STORE3 = QBASCFM
265          WRITE (6,399)
266      399 FORMAT (/T30,"INPUT DATA",//)
267          WRITE (6,400)
268      400 FORMAT (1H0,"WHAT IS THE THICKENED SLUDGE FEED RATE IN GPM ")
269          ACCEPT MOYNOGPM
270          IF (MODE.EQ.4) GO TO 418
271          WRITE (6,402)
272      402 FORMAT (1H0,"DO YOU WISH TO USE WOOD OR RDF AS THE AUXILLIARY
273         + FUEL ?",/T5,"INPUT A 'W' FOR WOOD OR AN 'R' FOR RDF")
274          READ (5,920) AUXFUEL
275          IF (MODE.LE.2) GO TO 445
276           GO TO 441
277      418 WRITE (6,420)
278      420 FORMAT (1H0,"WHAT IS THE WOOD FEED RATE IN TONS PER HR" )
279          ACCEPT WOODTPH
280          WRITE (6,430)
281      430 FORMAT (1H0,"WHAT IS THE RDF FEED RATE IN TONS PER HR" )
```

```
282           ACCEPT RDFTPH
283         438 WRITE (6,440)
284         440 FORMAT (1H0,"WHAT IS THE FUEL OIL FEED RATE IN GPM ")
285           ACCEPT OILGPM
286            GO TO 445
287         441 WRITE (6,442)
288         442 FORMAT (1H0,"WHAT IS THE DESIRED STEAM PRODUCTION IN LB/HR")
289           ACCEPT STEAMRT
290         445 SLUDGEWT = 8.33 * 60. * MOYNOGPM * TSTHICK / 100.
291           SLUDGEWT = SLUDGEWT/TS(1)*100.
292           SLUDGEGPM = SLUDGEWT / 60. /  8.33
293           OILWT = OILDENSITY * 60. * OILGPM
294            IF (LASTMODE.NE.6) TEMPIN = BOEXTEMP - 40.
295           IF (MODE.NE.4) GO TO 455
296           WOODWT = 2000. * WOODTPH
297           RDFWT = 2000. * RDFTPH
298           WRITE (6,450)
299         450 FORMAT (1H0,"WHAT IS THE DESIRED FAB RATE IN ACFM ")
300           ACCEPT ACFMFAB
301           GO TO 455
302         451 CONTINUE
303           IF (MODE.EQ.6) GO TO 453
304           WRITE (6,452)
305         452 FORMAT (1H0,T5,"INPUT THE DESIRED ECONOMIZER EXHAUST TEMP.")
306           ACCEPT BOEXTEMP
307           GO TO 455
308         453 WRITE (6,454)
309         454 FORMAT (1H0,T5,"INPUT THE DESIRED FAB TEMP.")
310           STORE4 = FABTEMP
311           STORE5 = OBATEMP
312           ACCEPT FABTEMP
313         455 CONTINUE
314           IF (MODE.EQ.1) GO TO 1000
315           IF (MODE.EQ.2) GO TO 2000
316           IF (MODE.EQ.3) GO TO 2000
317           IF (MODE.EQ.4) GO TO 4000
318           IF (MODE.EQ.5) GO TO 5000
319           GO TO 6000
500       C
501       C*************************************************************
502       C
503       C************** OUTPUT  SECTION ************************** C
504       C
505         500 WRITE (6,501)
506         501 FORMAT (///T35,"ENERGY BALANCE ")
507           WRITE (6,502) MOYNOGPM,TSTHICK,SLUDGEGPM,TS(1)
508         502 FORMAT(//T5,"THICKENED SLUDGE RATE",T32,F6.1," GPM",T50,"AT ",
509            +F4.1,"%TS", /T5,"TO COMBUSTOR SLUDGE RATE",T32,F6.1," GPM",
510            + T50,"AT ",F4.1,"%TS")
511           WRITE (6,503) WOODTPH,TS(2)
512         503 FORMAT(1H ,T5,"WOOD RATE",T32,F6.1," TPH",T50,"AT ",F4.1,"%TS")
513           WRITE (6,504) RDFTPH
514         504 FORMAT(1H ,T5,"RDF RATE",T32,F6.1," TPH")
```

```
515          WRITE (6,505) OILGPM,FUELHEAT/1E06
516       505 FORMAT(1H ,T5,"FUELOIL RATE",T32,F6.1," GPM",/T5,"TOTAL HEAT RELEA
517          +SE"T35,F5.1,T45,"MBTU/HR")
518          WRITE (6,506) OBASCFM,OBATEMP
519       506 FORMAT (1H ,T5,"OVER BED AIR",T35,F6.0,T45,"SCFM",T55,"AT",F6.0,
520          + T65," DEG F")
521          WRITE (6,507) ACFMFAB ,FABTEMP
522       507 FORMAT (1H ,T5,"FLUIDIZING AIR",T35,F6.0,T45,"SCFM",T55,"AT",
523          + F6.0,T65," DEG F")
524          WRITE (6,508) PNAIR
525       508 FORMAT (1H ,T5,"PNEUMATIC AIR",T35,F6.0,T45,"SCFM")
526          WRITE (6,509) TEMPHOT
527       509 FORMAT (1H ,T5,"COMBUSTOR EXHAUST TEMP.",T35,F5.0,T45,"F")
528          WRITE (6,510) BEDTEMP
529       510 FORMAT (1H ,T5,"MID BED TEMP.",T35,F5.0,T45,"F")
530          WRITE (6,511) STEAMPROD,BOEXTEMP
531       511 FORMAT (1H ,T5,"BOILER STEAM OUTPUT",T35,F7.0,T45,"LB/HR",
532          + T53," GAS EXIT TEMP",T68,F6.0,"DEG F")
533          WRITE (6,512) STEAMDEMAND
534       512 FORMAT (1H ,T5,"TURBINE STEAM DEMAND",T35,F7.0,T45,"LB/HR")
535          WRITE (6,513) WATERGPM,TEMPIN
536       513 FORMAT (1H ,T5,"SCRUBBER WATER INPUT",T35,F5.0,T45,"GPM",
537          + T53," GAS TEMP",F6.0,T71," DEG F")
538          WRITE (6,514) WATEROUT,TEMPOUT
539       514 FORMAT (1H ,T5,"SCRUBBER WATER OUTPUT",T35,F5.0,T45,"GPM",
540          + T53," GAS TEMP",F6.0,T71," DEG F")
541          WRITE (6,515) ACFMID
542       515 FORMAT (1H ,T5,"ID FAN FLOW RATE",T35,F6.0,T45,"ACFM")
543          WRITE (6,516) HPID
544       516 FORMAT (1H ,T5,"ID FAN POWER",T35,F5.0,T45,"HP")
545          WRITE (6,517) EA
546       517 FORMAT (1H ,T5,"EXCESS AIR",T35,F4.0,T45,"%")
547          WRITE (6,518) OXYCONC
548       518 FORMAT (1H ,T5,"COMBUSTOR EXHAUST OXYGEN",T35,F4.1,T45,"%")
600       600 IF (INVOKE2.EQ.0) GO TO 610
601          WRITE (6,605)
602       605 FORMAT (/T5,"THE HEAT INPUT IS NOT SUFFICIENT TO MAINTAIN MINIMUM
603          +",/,"  BED TEMP.")
604       610 IF (INVOKE3.EQ.0) GO TO 620
605          WRITE (6,615)
606       615 FORMAT (1H0,"-ID FAN CAPACITY HAS BEEN EXCEEDED")
607       620 IF (INVOKE4.EQ.0)  GO TO 630
608          WRITE (6,622)
609       622 FORMAT (1H0,"THE INPUT CONDITIONS ARE OUT OF RANGE FOR THIS
610          +",/,"  MODEL.")
611       630 IF (INVOKE5.EQ.0) GO TO 640
612          WRITE (6,633)
613       633 FORMAT (1H0,"THIS SLUDGE RATE IS TOO HIGH TO MAINTAIN ",
614          + /,"THE MINIMUM COMBUSTION TEMP.")
615       640 IF(INVOKE6.EQ.0) GO TO 650
616          WRITE (6,642)
617       642 FORMAT (1H0,"YOUR SLUDGE INPUT OR STEAM OUTPUT AS SPECIFIED
```

```
618         +",/," EXCEEDS THE BTU CAPACITY OF THE SYSTEM . ")
619       650 CONTINUE
620           GO TO 900
621       800 WRITE (6,801)
622       801 FORMAT (1H0,"THE AIR INPUT IS INSUFFICIENT FOR COMBUSTION")
623       900 WRITE (6,910)
624       910 FORMAT (/T5,"DO YOU WISH TO MAKE ANOTHER RUN? (Y/N) ")
625           READ (5,920) Q
626       920 FORMAT(A1)
627           IF (Q.EQ.Y) GO TO 245
628           STOP
1000      C*****************************************************************
1001      C
1002      C                       MAXIMUM STEAM OUTPUT MODE
1003      C
1004      C  THIS ANALYSIS WILL DETERMINE THE AUXILLIARY FUEL AND FAB
1005      C  INPUTS REQUIRED TO PRODUCE THE MAXIMUM POSSIBLE AMOUNT OF STEAM
1006      C  WHILE BURNING A SPECIFIED AMOUNT OF SLUDGE.
1007      C
1008      C
1009       1000 CONTINUE
1010            PNUMASS = PNAIR * .075 * 60.
1011            DENSITYFAB = .0973*(FABPRESS+407.)/(FABTEMP+460.)
1012            DENSITYOBA = .0973*(OBAPRESS+407.)/(OBATEMP+460.)
1013            OBAMASS = OBASCFM * DENSITYOBA * 60.
1014            SLUDGEBTU = SLUDGEWT * HHV(1) * TS(1) / 100.
1015            FUELHEAT = 104E06
1016       1040 BTUAUX = FUELHEAT - SLUDGEBTU - OILWT*HHV(4)
1017            IF (BTUAUX.LT.0) INVOKE6 = 1
1018            IF (INVOKE6.EQ.1) GO TO 640
1019            IF (AUXFUEL.EQ.W) GO TO 1050
1020            RDFWT = BTUAUX / HHV(3) / TS(3) * 100.
1021            WOODWT = 0.0
1022            GO TO 1060
1023       1050 WOODWT = BTUAUX / HHV(2) / TS(2) * 100.
1024            RDFWT = 0.0
1025       1060 CALL ULTIAN (SLUDGEWT,WOODWT,RDFWT,OILWT,FUELHEAT)
1026       1065 CALL AIR (STOICH, AIRMASS, AIRSCFM)
1027            FABMASS = AIRMASS - OBAMASS - PNUMASS
1028            ACFMFAB = FABMASS / DENSITYFAB / 60.
1029            IF (ACFMFAB.GT.FABMAX) GO TO 1070
1030            GO TO 1080
1031       1070 ACFMFAB = FABMAX
1032            GO TO 1095
1033       1080 IF (ACFMFAB.LT.FABMIN) GO TO 1090
1034            GO TO 1100
1035       1090 ACFMFAB = FABMIN
1036       1095  FABMASS =  ACFMFAB*DENSITYFAB*60.
1037            OBAMASS = AIRMASS - PNUMASS - FABMASS
1038            IF (OBAMASS.LE.0.) OBAMASS = 0.0
1039            AIRMASS = PNUMASS + OBAMASS + FABMASS
1040            OBASCFM = OBAMASS / DENSITYOBA / 60.
```

```
1041          EA = 100. * (AIRMASS/STOICH - 1.0)
1042          ROOTSAIR = ACFMFAB + OBASCFM
1043          IF (ROOTSAIR,GT,29000.) GO TO 1098
1044          GO TO 1100
1045     1098 FUELHEAT = FUELHEAT - 1.E06
1046          GO TO 1040
1047     1100 CALL FLUGAS (STOICH,AIRMASS,DRYGASWT)
1048          CALL TFLAME (FUELHEAT,FABMASS,OBAMASS,RATIO,TEMPHOT,
1049         + AIRMASS,HEATINPUT)
1050          IF (TEMPHOT,GT,EXHTEMPMAX) GO TO 1110
1051          GO TO 1120
1052     1110 EA = EA + 1.
1053          GO TO 1065
1054     1120 IF (TEMPHOT,LT,EXHTEMPMIN) GO TO 1130
1055          GO TO 1140
1056     1130 IF (OBAMASS,EQ,0.0,AND,ACFMFAB,EQ,FABMIN) GO TO 1132
1057          IF (EA,LE,5.0) GO TO 1132
1058          EA = EA - 1.
1059          GO TO 1065
1060     1132 INVOKE4 = 1
1061     1140 BEDTEMP = TEMPCALC (TEMPHOT,EA,H2OVF,FUELHEAT,DRYGASHEAT)
1062          IF (BEDTEMP,GT,TEMPHOT) BEDTEMP = TEMPHOT
1063     1180 CALL SCRUBR (DRYGASWT,GASMASSOUT,ACFMID,WATERGPM,DELTAWATER)
1064          WATEROUT = DELTAWATER /8.33/60. + WATERGPM
1065          HPID = 100. + .003 * GASMASSOUT
1066          IF (HPID,GT,HPMAXID) INVOKE3 = 1
1067          IF (ACFMID,GT,CFMMAXID) INVOKE3 = 1
1068          IF (INVOKE3,EQ,1) GASMASSOUT = 272.* HPMAXID
1069          CALL DEMAND (FABMASS,OBAMASS,GASMASSOUT,STEAMDEMAND)
1070          CALL BOILER (EFFICIENCY,STEAMPROD,HEATINPUT,BOEXTEMP)
1071          OXYCONC = (21.2 * EA) / (100. + EA)
1072          WOODTPH = WOODWT / 2000.
1073          RDFTPH  = RDFWT  / 2000.
1074          GO TO 500
2000     C*************************************************************
2001     C
2002     C                    MINIMUM AUXILLIARY FUEL MODE
2003     C               AND SPECIFIED STEAM PRODUCTION MODE
2004     C
2005     C  THIS ANALYSIS WILL DETERMINE THE MINIMUM AUXILLIARY FUEL
2006     C  INPUT REQUIRED TO BURN A SPECIFIED AMOUNT OF SLUDGE WHILE
2007     C  MAINTAINING ACCEPTABLE COMBUSTOR CONDITIONS.
2008     C
2009     C
2010      2000 INDEX = 0
2011          TEMPLAST = 3000.
2012          IF (MODE,EQ,2) STEAMRT = 0.
2013          PNUMASS = PNAIR * .075 * 60.
2014          DENSITYFAB = .0973*(FABPRESS+407.)/(FABTEMP+460.)
2015          DENSITYOBA = .0973*(OBAPRESS+407.)/(OBATEMP+460.)
2016          OBAMASS = OBASCFM * DENSITYOBA * 60.
2017          SLUDGEBTU = SLUDGEWT * HHV(1) * TS(1) / 100.
```

```
2018          IF (SLUDGEBTU.GT.104.E06.OR.STEAMRT.GT.45000.) INVOKE6 = 1
2019          IF (INVOKE6.EQ.1) GO TO 640
2020          ACFMFAB = FABMIN
2021          OILWT = 0.0
2022     2030 AIRKEEP = ACFMFAB*60.*DENSITYFAB + PNUMASS + OBAMASS
2023          BTUAUX = 0.0
2024          WOODWT = 0.0
2025          RDFWT  = 0.0
2026          IF (SLUDGEWT.EQ.0.0) WOODWT = 1.0
2027     2040 CALL ULTIAN (SLUDGEWT,WOODWT,RDFWT,OILWT,FUELHEAT)
2028     2050 CALL AIR (STOICH, AIRMASS, AIRSCFM)
2029          IF (AIRMASS.LT.AIRKEEP) AIRMASS = AIRKEEP
2030          FABMASS = AIRMASS - OBAMASS - PNUMASS
2031          ACFMFAB = FABMASS / DENSITYFAB / 60.
2032          EA = 100. * (AIRMASS/STOICH - 1.)
2033          CALL FLUGAS (STOICH,AIRMASS,DRYGASWT)
2034          INVOKE2 = 0
2035          CALL TFLAME (FUELHEAT,FABMASS,OBAMASS,RATIO,TEMPHOT,
2036         + AIRMASS,HEATINPUT)
2037          IF (INDEX.GT.0.AND.MODE.EQ.2) GO TO 2131
2038          IF (TEMPHOT.LT.EXHTEMPMIN) GO TO 2060
2039          GO TO 2110
2040     2060 BTUAUX = BTUAUX + 1.0E06
2041          IF (FUELHEAT.GT.104.E06) GO TO 2110
2042          IF (AUXFUEL.EQ.W) GO TO 2070
2043          RDFWT = BTUAUX / HHV(3) / TS(3) * 100.
2044          WOODWT = 0.0
2045          GO TO 2080
2046     2070 WOODWT = BTUAUX / HHV(2) / TS(2) * 100.
2047          RDFWT = 0.0
2048     2080 EA = STORE1
2049          GO TO 2040
2050     2110 IF (TEMPHOT.GT.EXHTEMPMAX) GO TO 2120
2051          GO TO 2130
2052     2120 IF (ACFMFAB.GE.FABMAX) INVOKE4 = 1
2053          IF (INVOKE4.EQ.1) GO TO 600
2054          EA = EA + 1.
2055          GO TO 2050
2056     2130 INDEX = 1
2057     2131 BEDTEMP = TEMPCALC (TEMPHOT,EA,H2OVF,FUELHEAT,DRYGASHEAT)
2058          IF (BEDTEMP.LT.BEDTEMPMIN) GO TO 2140
2059          GO TO 2151
2060     2140 IF (FUELHEAT.GT.104.E06) GO TO 2150
2061          GO TO 2060
2062     2150 INVOKE5 = 1
2063     2151 IF (BEDTEMP.GT.BEDTEMPMAX) GO TO 2152
2064          GO TO 2153
2065     2152 IF(BEDTEMP.GT.TEMPLAST) GO TO 2153
2066          TEMPLAST = BEDTEMP
2067          GO TO 2120
2068     2153 CALL SCRUBR (DRYGASWT,GASMASSOUT,ACFMID,WATERGPM,DELTAWATER)
2069          WATEROUT = DELTAWATER /8.33/60. + WATERGPM
2070          MPID = 100. + .003 * GASMASSOUT
```

```
2071          IF (HPID,GT,HPMAXID) INVOKE3 = 1
2072          IF (ACFMID,GT,CFMMAXID) INVOKE3 = 1
2073          IF (INVOKE3,EQ,1) GASMASSOUT = 272,* HPMAXID
2074          CALL DEMAND (FABMASS,OBAMASS,GASMASSOUT,STEAMDEMAND)
2075          CALL BOILER (EFFICIENCY,STEAMPROD,HEATINPUT,BOEXTEMP)
2076          OXYCONC = (21,2 * EA) / (100, + EA)
2077          IF (STEAMPROD,LT,STEAMDEMAND) GO TO 2190
2078          IF (STEAMPROD,LT,STEAMRT,AND,MODE,EQ,3) GO TO 2190
2079          GO TO 2250
2080     2190 INDEX = 0
2081          IF (FUELHEAT,LT,104,E06) GO TO 2060
2082          IF (ACFMFAB,GT,FABMIN,AND,EA,GT,5,) GO TO 2200
2083          GO TO 2250
2084     2200 EA = EA-1,
2085          GO TO 2050
2086     2250 CONTINUE
2087          WOODTPH = WOODWT / 2000,
2088          RDFTPH  = RDFWT  / 2000,
2089          GO TO 500
4000     C*****************************************************
4001     C
4002     C              EXHAUST TEMP MODE
4003     C
4004     C  THIS IS THE EXHAUST TEMP CALCULATION MODE WHICH IS SIMILAR TO
4005     C  THE OLD "NETWORK" AND "HEATWORK" PROGRAMS IN FUNCTION. WITH THIS
4006     C  MODE THE COMBUSTOR EXHAUST TEMP IS AUTOMATICALLY CALCULATED AND
4007     C  AN ENTIRE HEAT BALANCE CAN BE DONE IN ONE ITERATION.
4008     C
4009     4000 CONTINUE
4010          CALL ULTIAN (SLUDGEWT,WOODWT,RDFWT,OILWT,FUELHEAT)
4011          CALL AIR (STOICH, AIRMASS, AIRSCFM)
4012          PNUMASS = PNAIR * ,075 * 60,
4013          DENSITYFAB = ,0973*(FABPRESS+407,)/(FABTEMP+460,)
4014          DENSITYOBA = ,0973*(OBAPRESS+407,)/(OBATEMP+460,)
4015          FABMASS = ACFMFAB * DENSITYFAB * 60,
4016          OBAMASS = OBASCFM * DENSITYOBA * 60,
4017          AIRMASS = PNUMASS + OBAMASS + FABMASS
4018          IF (AIRMASS,GE.STOICH) GO TO 4010
4019     C
4020     C  IF CONTROL GETS TO HERE THE INPUT AIR IS SUBSTOICHIOMETRIC.
4021     C
4022          INVOKE1 = 1
4023          GO TO 800
4024     4010 EA = 100, * (AIRMASS/STOICH - 1,0)
4025          CALL FLUGAS (STOICH,AIRMASS,DRYGASWT)
4026          CALL TFLAME (FUELHEAT,FABMASS,OBAMASS,RATIO,TEMPHOT,
4027         + AIRMASS,HEATINPUT)
4028          BEDTEMP = TEMPCALC (TEMPHOT,EA,H2OVF,FUELHEAT,DRYGASHEAT)
4029          CALL SCRUBR (DRYGASWT,GASMASSOUT,ACFMID,WATERGPM,DELTAWATER)
4030          WATEROUT = DELTAWATER /8,33/60, + WATERGPM
4031          HPID = 100, + ,003 * GASMASSOUT
4032          IF (HPID,GT,HPMAXID) INVOKE3 = 1
```

```
4033          IF (ACFMID,GT,CFMMAXID) INVOKE3 = 1
4034          IF (INVOKE3,EQ,1) GASMASSOUT = 272.* MPMAXID
4035          CALL DEMAND (FABMASS,OBAMASS,GASMASSOUT,STEAMDEMAND)
4036          CALL BOILER (EFFICIENCY,STEAMPROD,HEATINPUT,BOEXTEMP)
4037          OXYCONC = (21,2 * EA) / (100, + EA)
4038          GO TO 500
5000     C
5001     C*********************************************************
5002     C
5003     C
5004     C          ECONOMIZER MODULE
5005     C
5006     C    THIS MODULE RUDUCES THE BOILER EXHAUST TEMP, DOWN TO
5007     C  EITHER THE SPECIFIED TEMP, OR THE MINIMUM POSSIBLE
5008     C  TEMP, (STEAM TEMP, AT 250 PSI SAT,) 350 DEG F,
5009     C
5010     C
5011      5000 CONTINUE
5012           IF (BOEXTEMP,LT,350,) BOEXTEMP = 350,
5013           GO TO 248
6000     C
6001     C************************************************
6002     C
6003     C
6004     C                AIR PREHEATER MODULE
6005     C
6006     C
6007     C     THIS MODULE SIMULATES THE PERFORMANCE OF AN AIR PREHEATER,
6008     C  HEAT IN THE FLUE GAS DISCHARGE IS USED TO HEAT THE FAB AND
6009     C  OVER BED AIR, THE TEMP OF THE HEATED AIR CANNOT EXCEED THE
6010     C  TEMP OF THE AIR HEATER DISCHARGE FLUE GAS,
6011     C
6012     C
6013      6000 CONTINUE
6014      6020 TEMPIN = BOEXTEMP - 40 + STORE4 - FABTEMP
6015           IF (TEMPIN,LT,FABTEMP) GO TO 6040
6016           GO TO 6060
6017      6040 FABTEMP = FABTEMP - 1,
6018           GO TO 6020
6019      6060 OBATEMP = FABTEMP
6020           LASTMODE = 6
6021           GO TO 248
9000           END
9001     C*********************************************************
9002     C
9003     C       BED TEMP, CALCULATION FUNCTION
9004     C
9005     C THIS FUNCTION IS DESIGNED TO ESTIMATE THE MID BED TEMP,
9006     C  THE FUNCTION WAS DESIGNED THROUGH A MULTIPLE LINEAR REGRESSION
9007     C  ANALYSIS OF A VERY LIMITED DATA SET,
9008     C FOR THAT LIMITED DATA SET THE MODEL CAN PREDICT THE TEMP,
9009     C  WITHIN + OR - 3%,
```

```
C
C*********************************************************
C
C
      FUNCTION TEMPCALC (TEMPHOT,EA,H2OVF,FUELHEAT,DRYGASHEAT)
      TEMPCALC = .914*TEMPHOT+3.47*EA-483.*H2OVF
      RETURN
      END
C
C*****************************************************
C
      SUBROUTINE ULTIAN(SLUDGEWT,WOODWT,RDFWT,OILWT,FUELHEAT)
      REAL NITROGEN
      DIMENSION FUELWT(4),FUEL(4),CHEM(6)
      COMMON/FUELS/ULTI(6,4),TS(4),HHV(4),STEAMIN
      COMMON/ELEMENTS/CARBON,HYDROGEN,OXYGEN,NITROGEN,SULFUR,ASH,WATER
      FUELWT(1) = SLUDGEWT
      FUELWT(2) = WOODWT
      FUELWT(3) = RDFWT
      FUELWT(4) = OILWT
C
C  THIS SUBROUTINE USES THE MASS INPUTS OF EACH FUEL AND THE
C  ULTIMATE ANALYSIS TO CALC THE TOTAL INPUT WEIGHTS OF EACH
C  ELEMENT AND WATER AND ASH
C
C  CALC OF WATER INPUTS AND PLACE ALL FUELS ON A DRY WT BASIS
C
C  NOTE - "STEAMIN" IS SLUDGE ATOMIZING STEAM
C
      FUELHEAT = 0.0
      WATER = STEAMIN
      DO 20 I=1,4
      WATER = WATER+FUELWT(I)*(1.0-(TS(I)/100.0))
      FUEL(I) = FUELWT(I) * TS(I) / 100.0
      FUELHEAT = FUELHEAT + FUEL(I) * HHV(I)
   20 CONTINUE
C
C  CALC OF ELEMENTAL INPUTS
C
C
      DO 30 I=1,6
      CHEM(I) = 0.0
      DO 30 J=1,4
   30 CHEM(I) = ULTI(I,J) * FUEL(J) / 100.0 + CHEM(I)
      CARBON   = CHEM(1)
      HYDROGEN = CHEM(2)
      OXYGEN   = CHEM(3)
      NITROGEN = CHEM(4)
      SULFUR   = CHEM(5)
      ASH      = CHEM(6)
      RETURN
      END
```

```
C*****************************************************************
C
C
      SUBROUTINE AIR (STOICH,AIRMASS,AIRSCFM)
      REAL NITROGEN
      COMMON/AERO/EA,HUMIDITY,TEMPAMB,PUMPHP,TEMPIN,TEMPOUT
      COMMON/ELEMENTS/CARBON,HYDROGEN,OXYGEN,NITROGEN,SULFUR,ASH,WATER
C
C
C  THIS SUBROUTINE CALCULATES THE STOICHMETRIC AIR MASS AND
C  TOTAL AIR MASS AND VOLUME
C  NOTE "AIRSCFM" IS AIR VOLUME AT STD. TEMP. AND PRESS.
C
      STOICH = 11.51*CARBON+34.3*HYDROGEN-4.32*OXYGEN+4.3*SULFUR
      AIRMASS = STOICH*(1.0+EA/100.0)
      AIRSCFM = AIRMASS/.075/60.
      RETURN
      END
C*************************************************************
C
C
      SUBROUTINE FLUGAS (STOICH,AIRMASS,DRYGASWT)
      REAL NITROGEN, N2MASS, N2VF
      COMMON/ELEMENTS/CARBON,HYDROGEN,OXYGEN,NITROGEN,SULFUR,ASH,WATER
      COMMON/GASSES/CO2MASS,H2OMASS,O2MASS,N2MASS,SO2MASS,FLUGASCFM,
     +CO2VF,H2OVF,O2VF,N2VF,SO2VF,DSCFM
      COMMON/AERO/EA,HUMIDITY,TEMPAMB,PUMPHP,TEMPIN,TEMPOUT
C
C
C  THIS SUBROUTINE CALCULATES THE MASS OF EACH FLUE GAS COMPOUND
C  THE VOLUME FRACTION OF EACH COMPOUND AND THE ACTUAL DRY VOLUME
C  AND DRY WT OF TOTAL COMBUSTOR EXHAUST
C
C
      AIRMASS = STOICH * (1.+EA/100.)
      CO2MASS = 3.6 * CARBON
      H2OMASS = 9.0 * HYDROGEN + WATER + AIRMASS * HUMIDITY
      N2MASS = .755 * AIRMASS + NITROGEN
      SO2MASS = 2.0 * SULFUR
      O2MASS =STOICH * EA/100.0 * .231
      DRYGASWT = CO2MASS+N2MASS+SO2MASS+O2MASS
C
C
C  TO CALCULATE THE VOL FRAC OF EACH COMPOUND THE VOLUME OF EACH ONE
C  MUST FIRST BE CALCULATED AND THAT VOL WILL BE STORED IN THE VOL
C  FRAC (VF) STORAGE REGISTERS UNTIL THE TOTAL VOLUME IS CALCULATED .
C
C
      CO2VF = 387. * CO2MASS / 44.
      H2OVF = 387. * H2OMASS / 18.
      N2VF  = 387. * N2MASS  / 28.
      O2VF  = 387. * O2MASS  / 32.
```

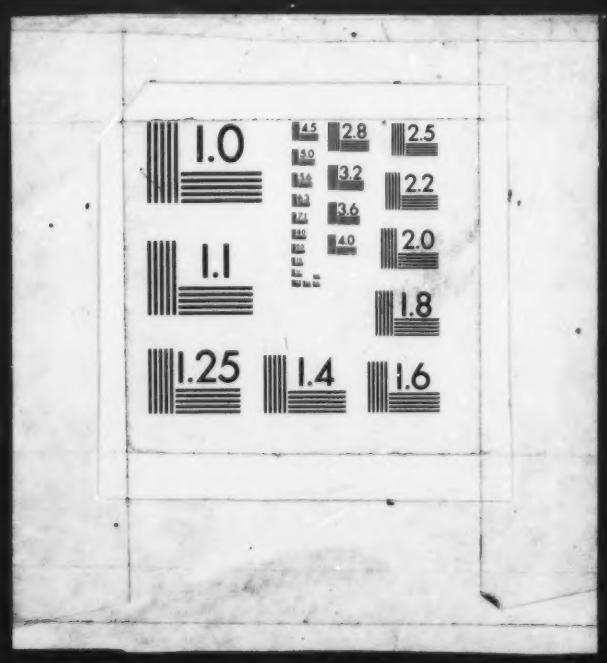
```
10093          SO2VF = 387. * SO2MASS / 64.
10094      C
10095      C  TOTAL AND DRY FLUE GAS VOL. IS CALCULATED AT STP (SCFM,DSCFM)
10096      C
10097          FLUGASCFM = CO2VF + H2OVF + N2VF + O2VF + SO2VF
10098          DSCFM = H2OVF
10099          CO2VF = CO2VF / FLUGASCFM
10100          H2OVF = H2OVF / FLUGASCFM
10101          N2VF  = N2VF  / FLUGASCFM
10102          O2VF  = O2VF  / FLUGASCFM
10103          SO2VF = SO2VF / FLUGASCFM
10104          FLUGASCFM = FLUGASCFM / 60.
10105          DSCFM = FLUGASCFM - (DSCFM/60.)
10106          RETURN
10107          END
10108      C*************************************************************
10109      C
10110      C
10111          SUBROUTINE TFLAME (FUELHEAT,FABMASS,OBAMASS,RATIO,TEMPHOT,
10112         + AIRMASS,HEATINPUT)
10113          REAL N2MASS,N2VF
10114          COMMON/INTEG/INVOKE1,INVOKE2,INVOKE3,INVOKE4,INVOKE5,INVOKE6
10115          COMMON/VALUES/FABTEMP,FABPRESS,FABMAX,FABMIN,OBASCFM,OBATEMP,OBA
10116         +PRESS,PNAIR,PNTEMP,EXHTEMPMAX,EXHTEMPMIN,BEDTEMPMAX,BEDTEMPMIN
10117          COMMON/FUELS/ULTI(6,4),TS(4),HHV(4),STEAMIN
10118          COMMON/GASSES/CO2MASS,H2OMASS,O2MASS,N2MASS,SO2MASS,FLUGASCFM,
10119         +CO2VF,H2OVF,O2VF,N2VF,SO2VF,DSCFM
10120          COMMON/AERO/EA,HUMIDITY,TEMPAMB,PUMPHP,TEMPIN,TEMPOUT
10121      C
10122      C  COMMON BLOCK GASSES IS INCLUDED HERE ONLY TO MAKE SURE
10123      C  IT WILL BE PASSED TO THE SUBROUTINE "HOTGAS"
10124      C
10125      C  THIS SUBROUTINE CALCULATES THE COMBUSTOR EXHAUST TEMP BY
10126      C  ITERATIVELY FINDING THE ADIABATIC FLAME TEMP OF ALL FUEL,
10127      C  AIR, AND OTHER ENERGY INPUTS TO THE FBC
10128      C
10129      C
10130      C  FIRST THE HEAT INPUT OF THE FAB AND OVER BED AIR (OBA) IS FOUND
10131      C
10132          FABHEAT = FABMASS * .24 * (FABTEMP - TEMPAMB)
10133          OBAHEAT = OBAMASS * .24 * ( OBATEMP - TEMPAMB )
10134      C
10135      C   HEAT INPUT WITH PNEUMATIC FUEL FEED AIR (PNU--)
10136      C
10137          PNUHEAT = PNAIR / .075 * .24 * (PNTEMP - TEMPAMB)
10138      C
10139      C  HEAT INPUT OF STEAM USED TO ATOMIZE THE SLUDGE (ATOM--)
10140      C
10141          ATOMHEAT = 1163.0   * STEAMIN
10142      C
10143      C  HEAT INPUT OF WATER VAPOR IN THE COMBUSTION AIR
10144      C
10145          HUMHEAT = AIRMASS * 1050. * HUMIDITY
```

```
10146     C
10147     C  TOTAL HEAT INPUT
10148     C
10149           HEATINPUT = FUELHEAT+FABHEAT+OBAHEAT+PNUHEAT+ATOMHEAT+HUMHEAT
10150     C
10151     C  INITIALIZE TO LOWEST ACCEPTABLE FLAME TEMP AND SEARCH UP
10152     C
10153           TEMPHOT = BEDTEMPMIN
10154           CALL HOTGAS (TEMPHOT,HEATOFGAS )
10155           RATIO = HEATINPUT / HEATOFGAS
10156           IF (RATIO.GT.1.0) GO TO 550
10157           INVOKE2 = 1
10157,1         TEMPHOT = TEMPAMB
10158     C
10159     C  IF CONTROL GETS TO HERE THE BEST POSSIBLE FLAME TEMP IS TOO LOW
10160     C
10161           RETURN
10162       500 RATIO = HEATINPUT / HEATOFGAS
10163       550 IF (RATIO.GE.1.10) GO TO 600
10164           IF (RATIO.GE.1.01) GO TO 700
10165           IF (RATIO.GE.1.001) GO TO 750
10166           GO TO 800
10167       600 TEMPHOT = TEMPHOT +100.
10168           GO TO 900
10169       700 TEMPHOT = TEMPHOT + 10.
10170           GO TO 900
10171       750 TEMPHOT = TEMPHOT + 1.
10172           GO TO 900
10173       800 IF (RATIO.LE..9991) GO TO 850
10174           RETURN
10175       850 TEMPHOT = TEMPHOT - 1.0
10176       900 CALL HOTGAS (TEMPHOT,HEATOFGAS)
10177           GO TO 500
10178           END
10179     C*********************************************************************
10180     C
10181     C
10182           SUBROUTINE HOTGAS (TEMPHOT,HEATOFGAS)
10183           COMMON/GASSES/CO2MASS,H2OMASS,O2MASS,N2MASS,SO2MASS,FLUGASCFM,
10184          +CO2VF,H2OVF,O2VF,N2VF,SO2VF,DSCFM
10185           COMMON/AERO/EA,HUMIDITY,TEMPAMB,PUMPHP,TEMPIN,TEMPOUT
10186           REAL N2MASS,N2VF
10187     C
10188     C  CONVERT TEMPERATURES TO RANKINE
10189     C
10190           THR = TEMPHOT + 460.
10191           TAR = TEMPAMB + 460.
10192     C
10193     C  CALCULATION OF ENTHALPIES PER MOLE AND PER POUND FOR EACH  COMPOUND
10194     C
10195           HCO2=16.2*(THR-TAR)-6530.*(ALOG(THR/TAR))+1410000.
10196          + *(1./TAR-1./THR)
```

```
C
      HCO2 = HCO2 /44.
C
C
      HH2O = 18973. + 19.86 * ( THR - TAR ) - 1194. * (SQRT(THR)
     + - SQRT(TAR)) + 7500. * ALOG(THR/TAR)
C
      HH2O = HH2O /18.
C
C
      HN2 = 9.47*(THR-TAR) - 3470.*(ALOG(THR/TAR))
     + +1160000.*(1.0/TAR-1.0/THR)
C
      HN2 = HN2 / 28.
C
C
      HSO2 = .148 * (THR - TAR) * 64.
C
      HSO2 = HSO2 /  64.
C
C
      HO2 = 11.515*(THR-TAR) - 344.*(SQRT(TAR))
     + + 1530. * ALOG(THR/TAR)
C
      HO2 = HO2 / 32.
C
C  TOTAL HEAT CONTENT OF THIS GAS AT "TEMPHOT"
C
      HEATOFGAS = CO2MASS*HCO2 + H2OMASS*HH2O + N2MASS*HN2
     + + SO2MASS*HSO2 + O2MASS*HO2
C
      RETURN
      END
C*********************************************************************
C
C
      SUBROUTINE SCRUBR (DRYGASWT,GASMASSOUT,ACFMID,WATERGPM,
     +DELTAWATER)
      REAL N2MASS,N2VF
      COMMON/GASSES/CO2MASS,H2OMASS,O2MASS,N2MASS,SO2MASS,FLUGASCFM,
     +CO2VF,H2OVF,O2VF,N2VF,SO2VF,DSCFM
      COMMON/AERO/EA,HUMIDITY,TEMPAMB,PUMPHP,TEMPIN,TEMPOUT
C
C
C  THIS SUBROUTINE CALCULATES THE FLOW RATE OF WATER REQUIRED
C  INTO THE SCRUBBER TO PROVIDE THE DESIRED SCRUBBER OUTLET
C  TEMPERATURE, IT ALSO DETERMINES WHAT FLOW RATE OF WATER
C  OUT OF THE SCRUBBER WILL OCCUR AT THOSE SAME CONDITIONS
C  THIS SUBROUTINE WILL  ALSO DETERMINE THE MASS AND VOLUME OF GAS
C  THAT MUST BE HANDLED BY THE INDUCED DRAFT FAN
C     IT IS ASSUMED THAT THE SCRUBBER OUTLET GAS AND DISCHARGE
C  WATER ARE AT THE SAME TEMP.
C
```

```
10250     C  EQUATIONS USED IN THIS ROUTINE ARE MODELS OF SMALL RANGES OF
10251     C  THE KEENAN AND KEYS STEAM TABLES.
10252     C
10253     C
10254     C  CALCULATION OF THE PARTIAL PRESSURE OF WATER VAPOR AT THE
10255     C  SCRUBBER OUTLET (PSIA)
10256     C
10257       100 PRESSOUT = EXP (16.625 - 9366./( TEMPOUT+460.))
10258           VOLFRACH2O = PRESSOUT / 14.7
10259     C
10260     C  CALC VOLUME OF TOTAL GAS OUTPUT FROM THE SCRUBBER
10261     C
10262           TOTALVOLOUT = DSCFM / (1.-VOLFRACH2O)
10263     C
10264     C  CALCULATION OF WATER MASS IN OUTPUT GAS (LB/HR) MASS=MPV/RT
10265     C
10266           H2OWT = 60.*(VOLFRACH2O*TOTALVOLOUT*18.)/(.7302*530.)
10267     C
10268     C  ENTHALPY CALC OF SUPERHEATED WATER VAPOR INPUT (FOR 200 TO 500 F)
10269     C
10270           HI = .47 *TEMPIN + 1053.6
10271           BTUH2OIN = HI * H2OMASS
10272     C
10273     C  CALC ENTHALPY OF SATURATED WATER VAPOR IN OUTLET GAS
10274     C
10275           HO = .43 * TEMPOUT + 1062.1
10276           BTUH2OOUT = HO * H2OWT
10277     C
10278     C  CALC OF MASS OF WATER REMOVED FROM FLUE GAS
10279     C
10280           DELTAWATER = H2OMASS - H2OWT
10281     C
10282     C  APPROX. ENTHALPY OF SCRUBBER WATER DISCHARGE
10283     C
10284           HWO = TEMPOUT - 31.7
10285           BTUWATER = DELTAWATER + HWO
10286     C
10287     C  CALC OF HEAT ABSOBED BY SCRUBBER WATER
10288     C
10289           STO1 = TEMPAMB
10290           TEMPAMB = TEMPOUT
10291           STO2 = H2OMASS
10292           H2OMASS = 0.0
10293           CALL HOTGAS(TEMPIN,DRYHEAT)
10294           TEMPAMB = STO1
10295           H2OMASS = STO2
10296           DELTABTU = BTUH2OIN - BTUH2OOUT - BTUWATER + DRYHEAT
10297     C
10298     C  MASS OF SCRUBBER WATER INPUT NEEDED TO ABSORB THAT MUCH HEAT
10299     C
10300           WATERGPM = DELTABTU / (TEMPOUT - TEMPAMB)
10301           WATERGPM = WATERGPM / 8.33 / 60.
```

2 OF 2
PB86
183 092



```
10302          IF ( WATERGPM.LT.1000. ) GO TO 300
10303          TEMPOUT = TEMPOUT + 5.0
10304          GO TO 100
10305     C
10306     C  CALCULATION OF GAS FLOW TO ID FAN (LB/HR AND ACFM AT FAN INLET
10307     C  TEMP. AND -60 IN. H2O PRESS.)
10308     C
10309       300 GASMASSOUT = DRYGASWT + H2OWT
10310          ACFMID = TOTALVOLOUT * (( TEMPOUT+460.)/ 530.) * 1.17
10311          RETURN
10312          END
10313     C*****************************************************************
10314     C
10315     C
10316          SUBROUTINE DEMAND (FABMASS,OBAMASS,IDMASS,STEAMDEMAND)
10317          REAL IDMASS
10318          COMMON/AERO/EA,HUMIDITY,TEMPAMB,PUMPHP,TEMPIN,TEMPOUT
10319     C
10320     C
10321     C  THIS SUBROUTINE CALCULATES THE STEAM DEMAND OF THE TURBINE
10322     C  DRIVES IN THE BUILDING 10 SYSTEM.
10323     C  IN THIS SIMPLIFIED MODEL THE FEEDWATER PUMPS AND SCRUBBER
10324     C  PUMPS ARE ASSUMED TO HAVE A CONSTANT COMBINED POWER INPUTT
10325     C  OF 175 HP.
10326     C  ACTUAL POWER OUTPUTS OF THE FAB AND ID FAN DRIVES ARE DETERMINED
10327     C  AND THE ASSOCIATED STEAM RATES AT THOSE TURBINE LOADS ARE
10328     C  APPROXIMATED.
10329     C
10330     C
10331     C THE PUMP DRIVES ARE SOLVED AT THE DEFAULT HP
10332     C
10333          PUMPSTEAM = 24.0 * PUMPHP
10334     C
10335     C  THE FAN DRIVES ARE SOLVED AT ACTUAL FLOW RATES
10336     C
10337          CFMFAB = ( FABMASS + OBAMASS ) / .075 / 60.
10338          HPFAB = 600.*SIN(4.32E-05*CFMFAB+.19)
10339          HPID = 100. + .003*IDMASS
10340     C
10341     C  CALC STEAM RATES ("SR") OF FANS ( LB-STEAM / HP-HR )
10342     C
10343          SRFAB = 31.0 - .01333 * HPFAB
10344          SRID =  31.0 - .01333 * HPID
10345     C
10346     C  CALC STEAM USAGE OF FAB AND ID FAN DRIVES
10347     C
10348          FANSTEAM = HPFAB * SRFAB + HPID * SRID
10349     C
10350     C  CALCULATION OF TOTAL TURBINE STEAM DEMAND
10351     C
10352          STEAMDEMAND = PUMPSTEAM + FANSTEAM
10353          RETURN
```

```
      END
C
C*****************************************************************
C
C
      SUBROUTINE BOILER (EFFICIENCY,STEAMPROD,HEATINPUT,BOEXTEMP)
      REAL NZMASS,NZVF
      COMMON/AERO/EA,HUMIDITY,TEMPAMB,PUMPHP,TEMPIN,TEMPOUT
      COMMON/GASSES/CO2MASS,H2OMASS,O2MASS,NZMASS,SO2MASS,FLUGASCFM,
     +CO2VF,H2OVF,O2VF,NZVF,SO2VF,DSCFM
C
C
C  THIS SUBROUTINE CALCULATES THE STEAM PRODUCTION RATE AND
C  EFFICIENCY OF THE DELTAK WASTE HEAT BOILER
C
C
C  BOILER EXHAUST TEMP (BOEXTEMP) COULD BE DETERMINED HERE
C
      TEMPHOT = BOEXTEMP
      CALL HOTGAS ( TEMPHOT,WASTEHEAT)
      OTHERLOSS = .10 * HEATINPUT
      BTURECOVER = HEATINPUT - WASTEHEAT - OTHERLOSS
      EFFICIENCY = 100.*BTURECOVER / HEATINPUT
      STEAMPROD = BTURECOVER / 1163.
      RETURN
      END
C*****************************************************************
C
C
      BLOCK DATA
      REAL NZMASS,NZVF,NITROGEN
      COMMON/INTEG/INVOKE1,INVOKE2,INVOKE3,INVOKE4,INVOKE5,INVOKE6
      COMMON/FUELS/ULTI(6,4),TS(4),HHV(4),STEAMIN
      COMMON/VALUES/FABTEMP,FABPRESS,FABMAX,FABMIN,OBASCFM,OBATEMP,OBA
     +PRESS,PNAIR,PNTEMP,EXHTEMPMAX,EXHTEMPMIN,BEDTEMPMAX,BEDTEMPMIN
      COMMON/AERO/EA,HUMIDITY,TEMPAMB,PUMPHP,TEMPIN,TEMPOUT
      COMMON/MAINS/OILDENSITY,HPMAXID,CFMMAXID,TSTHICK
      COMMON/ELEMENTS/CARBON,HYDROGEN,OXYGEN,NITROGEN,SULFUR,ASH,WATER
      COMMON/GASSES/CO2MASS,H2OMASS,O2MASS,NZMASS,SO2MASS,FLUGASCFM,
     +CO2VF,H2OVF,O2VF,NZVF,SO2VF,DSCFM
C
C
C  FUELS ARE 1.SLUDGE, 2.WOOD, 3.RDF, 4.FUEL OIL
C  CHEMICALS ARE 1.CARBON, 2.HYDROGEN, 3.OXYGEN, 4.NITROGEN,
C                5.SULFUR, 6.ASH
C
C
      DATA INVOKE1,INVOKE2,INVOKE3,INVOKE4,INVOKE5,INVOKE6/6*0/
      DATA ULTI/42.0,6.0,20.0,2.5,0.5,29.0,
     + 53.0,6.0,38.0,0.0,0.0,0.0,3.0,
     + 45.0,5.0,25.0,0.7,0.3,24.0,
     + 87.2,12.5,0.0,0.0,0.0,0.3,0.0/
```

```
      DATA TS/17.0,55.0,75.0,100.0/
      DATA HHV/7600.,8700.,6700.,19500./
      DATA STEAMIN/1000./
      DATA FABTEMP/140./,FABPRESS/60./,FABMAX/19000./,FABMIN/10500./,
     +     OBASCFM/0./,OBATEMP/140./,OBAPRESS/60./,PNAIR/3800./,
     +     PNTEMP/100./,EXHTEMPMAX/1750./,EXHTEMPMIN/1450./,
     +     BEDTEMPMAX/1450./,BEDTEMPMIN/1350./
      DATA EA/20./,HUMIDITY/.01/,TEMPAMB/70./,PUMPHP/175./,
     +     TEMPIN/430./,TEMPOUT/120./
      DATA OILDENSITY/7.28/,HPMAXID/610./,CFMMAXID/50000./,TSTHICK/6./
      DATA CARBON,HYDROGEN,OXYGEN,NITROGEN,SULFUR,ASH,WATER/7*0.0/
      DATA CO2MASS,H2OMASS,O2MASS,N2MASS,SO2MASS,FLUGASCFM,
     +CO2VF,H2OVF,O2VF,N2VF,SO2VF,DSCFM/12*0.0/
      END
```

```
  113          + PRODUCTION",/T5,"4. EXHAUST TEMP. (HEATWORK)",
         ^(1  )
LINES = 60
POLL = TRUE  (I,E, BATCH = FALSE)
REAR = TRUE (I,E, FRONT = FALSE)
DELTA =     1
CURRENT DEPTH = 0, THE DEPTH LIMIT = 10
RIGHT =72
LENGTH = 72
LONG = TRUE (I,E, SHORT = FALSE)
TIME = 50
TOTAL NUMBER OF CURRENT LINES = 997
FROM =     1
LEFT =  1
FIXED = TRUE (I,E, VARIABLE = FALSE)
SIZE = 0
DISPLAY = TRUE (I,E, QUIET = FALSE)
FORMAT=DEFAULT
NO TABS USED
FILES;
    WORK; K1911111
    KEEP;
    TEXT; MODEL.SYSTEC.DAYHO        MON, JUL  9, 1984, 11:11 AM
    JOIN;
```